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ALTERNATIVE TRANSPORTATION FUELS: REVIEW OF RESEARCH ACTIVITY IN CANADA

REPORT OF THE TASK FORCE ON ALTERNATIVE FUELS ASSOCIATE COMMITTEE ON PROPULSION NATIONAL RESEARCH COUNCIL CANADA

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National Research Council Canada

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Canada

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COMBUSTIBLES DE TRANSPORT DE REMPLACEMENT: EXAMEN DES TRAVAUX DE RECHERCHE AU CANADA

RAPPORT DU GROUPE DE TRAVAIL SUR LES COMBUSTIBLES DE REMPLACEMENT COMITÉ ASSOCIÉ SUR LA PROPULSION CONSEIL NATIONAL DE RECHERCHES DU CANADA

L. Gardner
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ABSTRACT

A review has been made of recent research and development activities in alternative fuels for transportation in Canada. The status of development of alternatives for gas turbines, diesels and spark ignition engines is discussed and recommendations are made for continuing research and development.

RÉSUMÉ

Un examen des travaux récents de recherches-développement sur les combustibles de remplacement dans le secteur du transport au Canada a été effectué. La situation du développement de combustibles de remplacement pour les turbines à gaz, les diesels et les moteurs à allumage par étincelle est analysée et des recommandations voulant que la recherche-développement soit poursuivie sont faites.

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1.0 SUMMARY AND RECOMMENDATIONS

1.1 Overview

In recent years much research and development effort in Canada has been devoted to alternative fuels. The principal motivation for this effort has been economic and strategic - to provide additional reasonably low cost fuels from domestic resources and thus to prevent excessive dependence on potentially high cost and insecure off-shore imports. An additional motivation is that good quality petroleum resources will eventually be consumed; we are already starting to see the degradation in quality of certain fuels.

The recent fall in world oil prices has, for the time being, obscured the urgency of substitution of petroleum-derived fuels but the long-term threat remains. We have no idea when the oil producing countries may again be able to throttle supply and force prices to double or triple. However, one of the major lessons of research on alternatives, learned from the reactions to crisis, is that a great deal of time and effort is required to develop satisfactory substitutes for petroleum-based fuels. Bearing in mind all of the criteria for successful fuelling of transport engines, it cannot be said that there is now an adequate inventory of substitute fuel technology which can be rapidly applied on a large-scale, should the need arise. The current relaxation of oil supply constraints allows time for the necessary research and development to be done.

For certain applications (e.g. aircraft) liquid petroleum-derived fuels are uniquely valuable, and the problem of fuel substitution in Canada is mainly related to the applicability of tar-sand-derived liquid fuels. The properties of these fuels can have important effects on ignition, extinction, emissions and engine durability; more research is needed on the ways in which fuel composition affects combustion behaviour.

For highway, rail, and marine transport a variety of liquid and gaseous fuel alternatives are potentially feasible. But all have substantial problems and require further work.

Owing to future restrictive solid particulate emission regulations for diesel engines (expected to be implemented in 1991, in the USA), the search for clean burning alternatives for truck and bus diesel fuel is of immediate importance. Possible alternatives include methanol, natural gas and propane, and tar sand derivatives (with particulate traps).

Natural gas and propane pose a variety of problems, including storage density (for natural gas, the possible need for liquifaction), safety, efficiency and emissions. These problems are especially acute with engines (spark or diesel) for which duel fuelling is required. For natural gas there are a variety of practical problems associated with gas compression, metering and dispensing.

Methanol fuel concerns include cold starting, corrosivity, emissions (notably aldehydes), flame visibility, lubricity and lubrication, and safety.

Tar sands derivatives for diesels can introduce problems with ignition and emissions.

These and other practical problems appear to be capable of solution but much applied research, and considerable basic research, on alternative fuels is still needed to develop the appropriate technology for safe, clean, economical and reliable use of these fuels in important classes of transport vehicles.

1.2 Gas Turbine Fuels

1.2.1 Aircraft gas turbine fuels

For the anticipated alternative fuels, the effects upon combustor performance have been fairly well established. Other than carbon formation/burn-out (and therefore heat transfer by radiation) the effects may be largely nullified by ensuring that constant droplet diameter is maintained at any operating condition for any specific chamber. Recent work indicates that a small fraction of the loss in efficiency may be due to fuel composition and/or structure. Although small, these effects may significantly effect pollution and further clarification is required.

It is certain that fuel composition significantly affects carbon formation. By itself, the hydrogen content establishes the gross effects, but second order effects appear to relate to other factors and considerable research will need to be done to establish the properties responsible for these effects. Residence times in the two zones (formation and burn-out) definitely play an important role in deciding the quantity of exhaust carbon. Here again, research is needed. Finally, it is very important to produce an exhaust carbon measurement technique which is accurate and capable of economic application to all types of combustion systems, in order that valid comparisons can be made.

From the viewpoint of development, the main problem is to design combustor walls capable of accepting the increased heat transfer without any loss of engine life. The obvious answer is that combustors should be designed for maximum radiation heat transfer (i.e. flame emissivity of unity) at all operating conditions. A major development response will be in improved wall cooling devices and/or the incorporation of ceramic coatings and possibly the development of ceramic combustors.

1.2.2 Industrial gas turbine fuels

- Solid Fuels: Solid fuel combustion in gas turbines is still so new that the major problems are developmental, and concerned largely with materials capable of tolerating ash and coke particles and high SO_x-bearing gases. Probably the pressurized, fluidized bed technology offers the best potential, especially

if an electrostatic precipitator can be developed to cope with particulate separation from high temperature gases.

- Liquid Fuels: Generally, the problems are similar to those of the aircraft gas turbine. If heavy fuels are used there is the additional problem of ash; high sulphur fuels also require special attention. It has been reported that, even with low sulphur fuels, conditions within the combustor can give rise to a higher proportion of SO_3 in the SO_x than other combustion systems. The resulting increase of the acid dew-point can increase stack corrosion. There would appear to be room for research on these phenomena. For fuels containing bound nitrogen, there is still much research required to find a satisfactory way of burning the fuel without excessive production of oxides of nitrogen (NO_x).

- Gaseous Fuels: There are few problems with high and medium calorific value fuels, but a greater understanding of the problems associated with low calorific value fuels is required. Research is required on the effects upon combustion rates and gaseous diffusion. The effects upon flame extinction characteristics are better known, but further work is still required. From the development viewpoint, there is the problem of how to prevent turbine mismatch without losing engine efficiency.

1.3 Gaseous Fuels for Reciprocating Engines

The gases which offer the most potential as alternative fuels are hydrogen, natural gas and propane (liquid petroleum gas LPG).

1.3.1. Hydrogen

Hydrogen has combustion properties which are excellent for engines, although storage and safety problems require serious attention. The main difficulty when considering its use as a transportation fuel is that presently, there is no indication as to when it could be made available in sufficient quantity to be considered as a practical alternative. Production of hydrogen from excess hydro power is a possibility but there remains the question as to whether the hydrogen produced in this manner might be better utilized for hydro-treating carbon-rich fuels such as tar sands products. Future sources of hydrogen could include fusion or solar furnaces but the development of such sources on a large scale would require many decades, even if the economic conditions were favourable to such development. Thus, it cannot be said that, in the near future, hydrogen can be considered an alternative transportation fuel available for widespread use.

1.3.2. Natural gas

- Gas composition: Variations in natural gas composition can significantly affect performance and durability of components. Variations in ethane and propane content can affect combustion

behaviour, e.g. flame speed, knock, optimum spark timing. The presence of water and hydrogen sulfide can affect the strength of gas storage vessels; there is a need for basic research to define fuel composition effects in general.

- Combustion characteristics: There is a potentially wide field of application for spark- ignition engines dedicated to natural gas fuelling. This calls for further research on the effects of compression ratio, speed, timing, and chamber and valve geometry on performance. The effects of swirl and other mechanisms of turbulence enhancement and control need to be specified. Much work is required on the effects of combustion conditions on emissions, especially NO_x. Various methods of enhancing flame speed need further study, along with side-effects such as enhanced heat transfer and associated mechanical problems.

  For natural gas fuelling of diesels with pilot diesel ignition, severe problems have been encountered with part-load inefficiency, excessive cylinder pressure maximum and rate of rise, and emissions. These problems arise from the mixing of the natural gas and air before entering the engine; at part load the gas-air ratio tends to be below the weak flammability limit. At high load, knocking can result. Throttling and preheating can partially alleviate these problems but the study of alternatives such as direct cylinder injection and alternative ignition mechanisms is necessary.

- Storage: The low energy density of compressed natural gas, even at 200 atm pressure, calls for further work to increase fuel storage density and vehicle range, and to reduce the danger of rupture of a high pressure cylinder. Current efforts to search for gas absorbing materials has produced some encouraging results but no breakthrough as yet. Substantial improvement has been made in the thermal insulation of liquified natural gas (LNG) tanks but these do not yet seem to be feasible for small vehicles.

- Safety: A variety of safety problems call for further research or development. These include the possibilities of corrosive failure of pressurized tanks and explosions due to gaseous fuel leakage within the vehicles, or within a garage or other enclosed space. Reliable sensors are needed for natural gas (particularly for LNG). In addition, further research and testing is needed for methods such as accoustic testing of the structural integrity of tanks.

- Gas Handling: Further design and development work is needed on equipment for compression, metering and dispensing of gaseous fuels. A particular need is for a safe, reasonably low-cost home compressor which could refuel a car overnight from a domestic natural gas supply. The problem of low cost, accurate, and reliable metering of natural gas over a wide range of fuel pressure has not yet been satisfactorily solved, nor has the

need been met for fully safe, reliable and low cost devices for transferring gaseous fuels from storage tanks to vehicles.

1.3.3. Propane

- Combustion Characteristics: For dedicated propane engines, the factors which govern optimum compression ratio in various kinds of combustion chambers need further research. Special measures may be necessary for cold starting of propane engines because natural gas emissions of the oxides of nitrogen may be a serious problem. Emissions of unburned hydrocarbons may also require development work to meet regulations which would be needed for the widespread use of gaseous fuels.

  Valve and seat wear, a problem with some propane engines, calls for appropriate metallurgical development.

- Safety: Though tank pressures are much lower than for compressed natural gas, propane tank integrity and the danger of accidental leakages of propane gas are serious concerns. Being heavier than air and having fairly wide flammability limits, propane gas can accumulate dangerously in enclosed spaces e.g. garages. There is a need to develop an automatic shut-off valve to eliminate the release of gas on fuelling. With prospective widespread use of propane as a vehicle fuel, leakage and dispersion, and measures to control ventilation, are important subjects.

- Gas handling: As for natural gas, the development of safe, reliable, accurate metering systems for vehicle fuelling is a necessity. A great deal of development work is required to bring fuelling station equipment to the level of safety and convenience which has been reached, over a long evolutionary period, for gasoline stations (though even in these stations fuel tank leakage, is not a rare problem).

1.4 Liquid Fuels for Reciprocating Engines

It is probable that in Canada alternative liquid fuels for reciprocating engines will essentially be of two types, i.e. alcohols and hydrocarbon-based fuels derived from tar sands, bitumen and heavy oil. The inclusion of the latter type as "alternative fuels" relates to the differences in their hydrocarbon structures and their composition, compared with fuels derived from conventional crude oil. These differences which are associated with both the nature of the bitumen and the severity of its processing, often requires a technical assessment of their effect on combustion performance.

- Alcohols: Because of the availability of large reserves of natural gas from which methanol can be conveniently produced, alcohol may play a prominent role as an alternative fuel for gasoline in spark ignition engines. It is also possible that methanol will find use as an alternative fuel for diesel engines, especially if attempts to develop particulate traps are unsuccessful. Although it might require ignition assistance, the use of methanol in diesel engines could provide substantial reduction of particulate emissions.

- Low Level Alcohol Blends (typically up to 10% alcohol content): At the present time, a limited quantity of a low level methanol/gasoline blend is being sold in Canada. This blend contains 5% methanol and 3% co-solvent (either ethanol, TBA or IPA). The low level blends are intended for use in current vehicles and distribution systems. Problems associated with low level blends include miscibility, water tolerance (precipitation in the presence of water), volatility, driveability, corrosion, and the measurement and interpretation of octane ratings. The need to use a co-solvent (usually a higher alcohol) to achieve solubility significantly affects its cost and availability. Low level blends are considered "convenient" because they are reasonably compatible with current vehicles and distribution systems, and they provide octane improvement. Their role in provision of alternative fuels for spark ignition engines can be seen as transitional; they could conceivably provide 10% substitution with a minimum of time and effort. The major move would be toward the fuel alcohols.

- Fuel alcohols: Fuel alcohols are defined as fuels containing 85% (or more) alcohol, the remainder being gasoline or a mixture of other hydrocarbons added to improve volatility and to provide flame visibility. Fuel alcohols require purpose-built vehicles, to overcome problems with cold starting, driveability, materials compatibility and lubricity, and to take advantage of benefits that can be gained with alcohol (such as high knock resistance, broader flammability limits, higher flame speed, and lower flame temperature and emmisivity). Some interesting research and field testing on so-called "flexible fuel" vehicles is underway. Such technology permits vehicles to handle fuels ranging from 100% gasoline to 95% methanol and, therefore, such vehicles are not constrained by the existing retail fuelling infrastructure.

- Alcohols as diesel fuels: Alcohols have very low cetane numbers and, hence, poor ignition characteristics (ignition delay) in diesel combustion. For these and other reasons, the use of alcohols in diesel engines is far behind their use in spark ignition engines. However, the possible benefits associated with reducing particulate emissions has motivated efforts to overcome these problems. There is interest in the use of diesel fuel/methanol emulsions containing between 5-30% methanol diesel fuel stabilized with up to 7% emulsifier, and the use of

methanol containing 10-20% ignition improver. Cost is a significant factor with the use of both the emulsifier and the ignition improver. However, the major effort is directed towards modifying the diesel engine to assist ignition, using glow or spark plugs, as an alternative approach to the solution of ignition problems associated with the use of methanol. The major obstacles to using alcohols in diesel engines are ignition and compatability with materials. Another difficulty with methanol, which also applies to its use as an alternative for gasoline, is its wide range of flammability (over a temperature range typical of ambient) combined with low flame luminosity.

The fact that methanol is flammable over a typical ambient temperature range is a significant hazard. The toxological risk of methanol compared to gasoline needs to be fully characterized. Since diesel fuels normally have flash points in excess of 38°C, they are classified as combustible rather than flammable by the NFPA (National Fire Protection Association), a classification used for design and regulation purposes. Diesel storage and distribution systems are constructed on the basis of the flash point exceeding 38°C. To accommodate flammable liquids (such as gasoline) fire safety requirements and regulations for construction are more stringent. The use of methanol as a diesel fuel (even in diesel fuel/methanol blends) will reduce the flash point and current facilities and operating practices may not be acceptable.

- Tar sands-derived fuels: The composition of tar sands-derived crude oil is such that almost 50% occurs in the middle distillate boiling range and, consequently, provides a significant source for diesel fuels. However, the high aromatic nature of the crude means that (unless corrected) the hydrogen deficiency of these diesel fuels will result in poor ignition characteristics. Work has been done, and more is continuing, to determine the effect of low cetane fuel on engine performance and durability. The establishment of a 35 minimum cetane number as a "1990" target, compared with the current 40 minimum, has now been moved beyond the end of the 20th century, in light of the recent crude oil supply situation. Engine research work on this problem is of importance, since using hydrogenating to increase the fuel cetane number is expensive in terms of energy and dollars. A major area of study, which is applicable to all types of diesel fuels, is that of particulate and oxides of nitrogen emissions. Work to relate the effect of the chemical species found in tar sands-derived diesel fuel upon these emissions is another important part of future research programs.

Although the tar sands crude is highly aromatic it is not particularly suitable for gasoline production because of the paraffinic nature of its naphtha fraction. The majority of the highly substituted aromatics fall in the middle distillate range; lighter aromatics that raise the octane number are absent. It is considered that this

situation can only be changed by increasing the severity of the hydrogenation processing in future tar sands projects.

- Engine and combustion research: Combustion of fuel in an engine is a process that involves interaction between the engine and the fuel. Therefore, in addition to the need for alternative fuel research, there exists a need to pursue engine research and development to accommodate or exploit the alternative fuel properties. For spark ignition engines, design modifications to take advantage of certain alcohol properties are essential. In diesel combustion, modifications such as staged fuel injection will enable lower cetane fuel to be used. The use of ceramics, with superior high temperature properties will provide an opportunity to utilize higher combustion chamber temperatures in diesel engines. This will provide an advantage in terms of ignition delay and in the ability to utilize residual fuel components. Ceramic valves, guides and seats may also provide additional resistance to the corrosion associated with the sodium and vanadium present in the residuals.

1.5 Recommendations

It is recommended that:

1. federal and provincial government agencies be urged to continue support for alternative fuels research, so that adequate technology can be developed before the next fuel supply crisis develops,

2. further research effort be devoted to specific technical problems identified in this report and summarized in Section 6.0,

3. provision be made for analysis and dissemination of the results of work to date and of the rationale for further work.

2.0 INTRODUCTION

2.1 Objective and Scope of Work

The work, whose results are described in this report, was undertaken by a task force established by the Associate Committee on Propulsion (ACOP) of the National Research Council. The terms of reference of ACOP are:

1. to advise the National Research Council, federal departments and other organizations regarding research and development requirements in the field of propulsion;

2. to bring together specialists from various disciplines involved in the field of propulsion, in order to formulate guidelines for research and development;

3. to participate in co-ordinating relevant research and development in universities, government laboratories, and industry, with the aim of establishing a strong, Canadian-based expertise;

4. to constitute subcommittees for the study of specific problems as may be required;

5. to act as a focal point for the exchange of technical information nationally and internationally, in the field of propulsion;

6. to carry out other related activities, as may be assigned by the National Research Council from time to time.

The membership of this task force consisted of:

L. Gardner, National Research Council
P. Hallett, Transport Canada
P. Hill, University of British Columbia, Chairman
B. James, Energy Mines and Resources Canada
J. Odgers, Laval University

and the activities were to:

(i) review the progress in fundamental research on combustion of alternative fuels for engines, e.g. ignition quality, ignition delay, knock, flame speed, flammability limits, heat transfer, emissions;

(ii) identify needs for further research of practical importance;

(iii) identify any needs for communication, coordination or cooperation in such research; and

(iv) advise ACOP on whether it could play a useful role in encouraging basic research on alternative fuels through periodic assessment, symposiums and publication activities.

2.2 Needs for Alternative Fuels Research

Given the current adequacy of gasoline supplies, and the excess world production capacity of petroleum, the urgency of research and development on alternatives may seem to have disappeared. However the problem has not disappeared; it has merely been postponed. It can be argued that the current situation allows us the necessary "breathing space" to bring on-stream alternative fuel options that make the most economic sense, and in a manner least disruptive to our transport system. It is important to recognize that:

(i) cartel control of world oil supply could be re-established on short notice;

(ii) long lead times are required to develop the appropriate technology, regulations, and distribution capacity whereby alternative fuels can be made available in the marketplace;

(iii) reduction in the rate of growth of oil demand has been associated with world-wide economic recession and energy conservation; return to economic growth could rapidly increase the demand for oil (there is already evidence of this in some sectors);

(iv) in any case, quality petroleum resources will inevitably decline in the near future;

(v) reduction in gasoline consumption has been due, in large part, to down-sizing of passenger vehicles and, less so, to increases in engine efficiency. (Over the last 10 year period the reduction in average fuel consumption per vehicle has been around 50%. However, it is important to recognize that this reduction has taken a decade to achieve and that most of the reduction which is feasible may already have been realized. One cannot count on mitigating the effects of the next oil supply crisis by further substantial reductions in vehicle fuel consumption, especially through more down-sizing.);

(vi) experience with alternative fuels during the past 10 years has shown that, while a variety of fuels could be used to propel a given vehicle under emergency conditions, the use of these fuels on a large scale over a long period of time could have unacceptable consequences on emissions to the environment, engine durability, engine operability (e.g. in cold weather), safety, or in total cost of operation. Much time is needed to do the necessary research and development to provide fully satisfactory alternative fuelling on a large scale.

Protection against future scarcity or excessive prices of offshore fuel feedstocks is only one of the major motivations for

continuing work on alternative fuels. A second has to do with environmental problems which, quite independently, could force changes in fuel sources. Increasingly severe restrictions on diesel particulate emissions, for example, are forcing the search for alternatives to diesel fuel. It is not certain that a satisfactory and durable diesel particulate trap can be developed. Work is underway to examine the feasibility of substituting methanol or methanol-diesel blends as a means of reducing particulates and NO_x emissions. The immediate impetus for this work is provided by announced future changes in U.S. diesel emissions regulations; it is argued that Canada will follow in due time (Canada has already indicated its adoption of the 1988 standards).

For buses and trucks, there is need to assess the relative feasibility of natural gas, propane, or methanol and diesel fuel (with some kind of particulate trap). Of course feasibility is not solely a matter of engine technology; systems for fuel processing, delivery, storage and dispensing must also be considered. Many of the requisite operations are hazardous to some extent, and safety-related research and development is widely needed.

Examples of requirements for safety-related research include:

- particular dangers arising from alcohol fires because the flame may not be visible;

- dangers of accumulating inflammable fuel vapour mixtures in air in enclosed spaces, within vehicles or within vehicle storage spaces;

- dangers of rupturing pressurized fuel tanks during vehicle crashes.

Another area in which further research is needed affects the durability of engines using alternative fuels and concerns the interaction of these fuels with materials found in fuel delivery lines and controls, and inside engines. Certain fuels have deleterious effects on engine lubrication. Wear on valves and valve seats, and piston erosion can be just some of the problems.

The adverse behaviour of certain fuels in cold temperatures is also an area for continuing research. Low volatility may produce cold starting problems. Alternative liquid diesel fuels may need additive components or special methods of heating or ignition may need to be supplied. Cold weather driveability is a particularly difficult problem for methanol and methanol-gasoline blends.

Fundamental research is called for in the combustion behaviour of alternative fuels to determine optimum conditions for their use in engines dedicated to one fuel. Natural gas, for example, tends to have a low burning velocity at high pressure, and special methods, e.g. turbulence enhancement, may be called for to improve burning velocity and to thereby increase fuel economy and reduce the emission of pollutants.

Gaseous fuel alternatives have low energy storage density compared to gasoline such that, for a given fuel container volume, vehicle range with these fuels may be inferior to that of conventionally fuelled vehicles. Methods of increasing fuel density, e.g. pressurization, liquefaction, or absorption of gases, are still under development.

Certain alternative fuels have their own environmental problems, e.g. aldehydes and other possible toxic components can be the result of methanol combustion. Research on methods to measure these emissions and to characterize their harmful effects, as well as to develop emissions control techniques, is needed.

The requirements for research on alternative fuels are many and varied.

2.3 Review of Canadian Research and Development Activity

A survey of Canadian research and development work on alternative fuels for transportation, undertaken in recent years, has provided details for over 100 projects. These details, provided in Appendix A, are arranged in alphabetical order of the organization conducting the research.

The Canadian activity is, of course, only part of the larger international effort on alternative fuels. The principal lessons learned from this world-wide effort are included in Sections 3.0, 4.0 and 5.0, but in this Section we restrict our attention to the Canadian effort only. It is appropriate to do this, since many of the factors influencing the adoption of a given alternative fuel in a given country have more or less importance, depending on which country is considered. The factors include: fuel resources, climate, emissions, potential market size, regulations, and government policy on the subsidy of alternative fuels.

In Canada, for example, we have vast reserves of tar sands and large resources of natural gas. We do not yet have a huge market potential for alternative fuels, so that most of the work so far has been devoted to retrofitting existing engines, rather than to the design and building of engines devoted to a specific alternative fuel. (This situation is beginning to change.) With its cold climate, Canada needs fuels which are specially suited to starting an engine at low temperatures. Our emissions regulations tend to follow the increasingly severe U.S.A. regulations, and this provides both opportunity and difficulty for the widespread development of alternative fuels.

Table 2.1 shows the approximate distribution of effort in alternative fuels in Canada, during recent years, according to fuel type and institutional classification. The numbers are approximate because the survey (whose detailed results are in Appendix A) may not be complete and because some projects have had to be arbitrarily classified. Some projects involve large expenditures; some relatively small. Some projects are continuing; some have been completed. Largely excluded from this review have been projects which may be classified as "demonstration" rather than "research or development".

Table 2.2 shows the distribution of projects on alternative fuels for gas turbines, mentioning the organizations, fuel types and abbreviated project titles. Table 2.3 does the same for spark-ignition engines and Table 2.4 for diesel engines.

Overall, an important Canadian effort has been made to alternative fuel development, although the total level of support appears to have greatly diminished in the past year or two. In view of potential future needs, it is worthwhile to assess the progress that has been made and the problems remaining in the application of alternative fuels to transportation in Canada.

Fuel	Research Organizations	Industrial	Universities	Total Projects
Propane	7	5	9	21
Natural Gas	18	5	26	49
Hydrogen	1	1	6	8
Methanol and Methanol Blends	13	0	5	18
Ethanol and Ethanol Blends	3	0	1	4
Tar Sands Derivative	4	3	5	12
Ammonia	1	1	0	2
Gas Turbine Fuels	7	3	2	12
Total/Institution	54	18	54	126

TABLE 2.1: Numbers of Recent and Continuing Projects

TABLE 2.2: Alternative Fuels for Gas Turbine Engines

ORGANIZATION	PROJECT TITLE
Tar Sands Derivatives	
National Research Council (2)	Development of Laser diagnostic techniques for combustion systems (in gas turbines)
National Research Council (6)	Fuel analysis
National Research Council (9)	Fuel sprays and combustion
Pratt & Whitney Canada	Alternative fuels combustion research
Royal Military College (9)	Bluff body flame stabilization
Universite Laval (2)	Behaviour of alt. fuels in small transparent combustor ... etc.
Oil Shale Derivative	
Pratt & Whitney Canada	Alternative fuels combustion research
Universite Laval (2)	Behaviour of alt. fuels in small transparent combustor ... etc.
Process Gas	
Universite Laval (1)	Combustion of gaseous fuels in various oxygen-inert mixtures ... etc.
Natural Gas	
Universite Laval (1)	Combustion of gaseous fuels in various oxygen-inert mixtures ... etc.
Propane/LPG	
Universite Laval (:1)	Combustion of gaseous fuels in various oxygen-inert mixtures ... etc.
Oxygen with Gasoline	
National Research Council (6)	Fuel Analysis
Other Fuels	
National Research Council (1)	Combustion modelling in a through flow combustor
National Research Council (2)	Development of laser diagnostic techniques for gas turb. comb. system
National Research Council (3)	Mean droplet size distribution measurement
National Research Council (4)	Droplet size and velocity measurements
National Research Council (5)	Development and application of optical diagnostic techniques to gas turb.
Universite Laval (1)	Combustion of gaseous fuels in various oxygen-inert mixtures ... etc.
Universite Laval (2)	Behaviour of alt. fuels in small combustors ... etc.
Westinghouse Canada Inc. (1)	Fuel forwarding and emissions from burning naphtha in industrial gas turb.
Westinghouse Canada Inc. (2)	Crude and residual oils as gas turbine fuels

TABLE 2.3: Alternative Fuels for Spark Ignition Engines

ORGANIZATION	PROJECT TITLE
Process Gas	
Bombardier Inc. (1)	Dual fuelling of a diesel engine with natural gas
University of Calgary (6)	Methane and propane for spark ignition engines
Natural Gas	
B.C. Research Council (1)	Safety testing
B.C. Research Council (2)	Conversion kit evaluation
B.C. Research Council (3)	Effect of spark plug gap on engine performance
B.C. Research Council (5)	Natural gas storage density
B.C. Research Council (6)	CNG compressors
Bombardier Inc. (1)	Duel fuelling of a diesel engine with natural gas
Chemetics International Co. (1)	Safety of natural gas for vehicle fuelling
CNG Fuel Systems Inc. (1)	Fuel injection system for natural gas fuelling of spark ignition engines
Ecole Polytechnique	Effect of natural gas on S.I. engine performance
Energy mines & Resources (1)	Emissions with natural gas fuelling
Energy Mines & Resources (3)	Natural gas as an automotive fuel
Ont. Min. Transport & Comm. (10)	In use evaluation of CNG home compressor
Ont. Min. Transport & Comm. (11)	Development of improved & cost effective carbon adsorbents for storing CNG
Ont. Min. Transport & Comm. (13)	Assessment of cold start performance of CNG and propane vehicles
Ont. Min. Tarnsport & Comm. (14)	Natural gas vehicle conversion kits
Ontario Res. Foundation (1)	Durability of spark ignition engine using natural gas
Ontario Res. Foundation (2)	Spark ignition propane engine
Royal Military College (1)	Composite carbons for methane absorption
Royal Military College (2)	Adsorption of natural gas on porous carbons
Royal Military College (3)	Solid absorbents for natural gas for automotive use
Royal Military College (5)	Absorption of methane by composite carbons
Transport Canada (1)	Safety of natural gas as a ground transportation fuel
Transport Canada (2)	Safety of natural gas fuelled vehicles
University of Alberta (1)	Knock detection in engines
University of B.C. (1)	Performance of a single cylinder engine with natural gas fuelling
University of B.C. (2)	Laminar flame velocity of methane in air with ethane and propane additive
University of B.C. (3)	Performance of a single cylinder research engine fuelled with natural gas
University of B.C. (5)	Performance of a spark ignition engine with gasoline and natural gas
University of B.C. (7)	Squish-generated turbulence in S.I. engines
University of Calgary (2)	Safety of engine operation with natural gas, gasoline, propane and hydrogen
University of Calgary (9)	Ignition limits with methane fuelling
University of Toronto (2)	Storage of compressed natural gas and hydrogen
University of Toronto (3)	Testing and evaluation of automotive propane and natural gas conversion
University of Victoria	High energy ignition with natural gas fuelling
Methanol	
Manitoba Research Council (1)	Review of methanol fleet tests
Manitoba Research Council (2)	Engine wear and material compatibility with methanol/fuel
Manitoba Research Council (3)	The Manitoba neat methanol fleet tests
Manitoba Research Council (4)	M85 methanol/gasoline blend vehicle fuel demonstration
Manitoba Research Council (7)	The Manitoba methanol fleet test
Manitoba Research Council (8)	Manitoba methanol fleet test (CGSB 4.75, Methanol 4.75, 9BA blend)
Ont. Min. Transport & Comm. (8)	Modelling of methanol engine cold-starting
Ont. Min. Transport & Comm. (9)	Durability evaluation of methanol fuelled vehicles

TABLE 2.3: Alternative Fuels for Spark Ignition Engines (continued)

ORGANIZATION	PROJECT TITLE
Methanol (continued)	
Ontario Res. Foundation (4)	Performance of methanol blends in spark ignition engines
Ontario Res. Foundation (5)	Safety of methanol use in transportation
Royal Military College (6)	Cold starting of methanol fuel blends
Universite Laval (3)	Alternative fuels for gasoline engines
University of Toronto (7)	Cold starting of methanol-fuelled S.I. engines
Ethanol	
Manitoba Research Council (6)	Gasohol Fleet Test
Universite Laval (3)	Alternative fuels for gasoline engines
Propane/LPG	
Energy Mines & Resources (2)	Propane as an automotive fuel
Manitoba Research Council (5)	Propane fleet test
Ont. Min. Transport & Comm. (13)	Assessment of cold start performance of CNG and propane vehicles
Ontario Res. Foundation (3)	Propane fuelled spark-ignition engine
Transport Canada (2)	Safety of gas fuelled vehicles
University of Alberta (1)	Knock detection in engines
University of Alberta (2)	Plasma ignition systems
University of Calgary (2)	Safety of engine operation with natural gas, gasoline, propane and hydrogen
University of Calgary (6)	Methane and propane for spark ignition engines
University of Toronto (3)	Testing and evaluation of automotive propane and natural gas conversion
Hydrogen	
Chemetics International Co. (3)	Hydrogen safety
University of Calgary (2)	Safety of engine operation with natural gas, gasoline, propane and hydrogen
University of Toronto (2)	Storage of compressed natural gas and hydrogen
University of Toronto (4)	Design of safe hydrogen fuel system for engine testing
University of Toronto (6)	Hydrogen fuelling of spark ignition engines
Ammonia	
Chemetics International Co. (2)	Ammonia fuel
Oxygenates with Gasoline	
Manitoba Research Council (3)	The Manitoba neat methanol fleet test
Manitoba Research Council (4)	M85 methanol/gasoline blend vehicle fuel demonstration
Mantioba Research Council (6)	Gasohol fleet test
Manitoba Research Council (7)	The Manitoba methanol fleet test
Manitoba Research Council (8)	Manitoba methanol fleet test (CGSB 4.75, methanol 4.75, 9BA blend)
Ont. Min. Transport & Comm. (8)	Modelling of methanol engine cold-starting
Ontario Res. Foundation (9)	Performance of S.I. engine vehicle with methanol/gasoline blends
Royal Military College (6)	Cold starting of methanol fuel blends
University of Ottawa (2)	Properties of alcohol gasoline blends
Other Fuels	
Universite Laval (3)	Alternative fuels for gasoline engines
University of Toronto (8)	Operability and emissions of a S.I. engine with decomposed methanol fuel

TABLE 2.4: Alternative Fuels for Diesel Engines

ORGANIZATION	PROJECT TITLE
Tar Sands Derivatives	
Canadian National Railways	Operation of railroad diesel engines on lower quality fuels
Esso Petroleum Canada (1)	Effect of diesel fuel composition on performance
National Research Council (6)	Fuel analysis
National Research Council (7)	Future diesel fuels
National Research Council (9)	Fuel sprays and combustion
Royal Military Colelfe (8)	Ignition delay
University of Ottawa (1)	Performance of a two-stroke diesel on tar sands derivative fuel
University of Ottawa (4)	Ignition of multicomponent liquid fuels
Process Gas	
Bombardier Inc. (1)	Dual fuelling of a diesel engine with natural gas
University of Calgary (6)	Methane and propane for spark igniton engines
Natural Gas	
B.C. Research Council (4)	Electronic dual-fuel diesel control system
B.C. Research Council (5)	Natural gas storage density
B.C. Research Council (6)	CNG compressors
Bombardier Inc. (1)	Dual fuelling of a diesel engine with natural gas
Chemetics International Co. (1)	Safety of natural gas for vehicle fuelling
CNG Fuel Systems Inc. (2)	Metering of natural gas
Concordia University (1)	Injection & ignition of hydrogen in compress. ignition engines.
Concordia University (2)	Injection & ignition of natural gas in diesel engines
DSMA Acton Ltd.	Dual fuelling of a two-stroke C.I. engine with natural gas
Ont. Min. Transport & Comm. (1)	Mississauga Transit natural gas bus demonstration
Ont. Min. Transport & Comm. (10)	In use evaluation of CNG home compressor
Ont. Min. Transport & Comm. (11)	Development of improved & cost effective carbon adsorbents for storing CNG
Ont. Min. Transport & Comm. (3)	Development and optimization of Dereco propane and natural gas engines
Ont. Min. Transport & Comm. (4)	Natural gas testing and conversion of an 8.2 L Detroit diesel engine
Ont. Min. Transport & Comm. (5)	Conversion of medium-duty Cummins L10 diesel engine to natural gas
Royal Military College (1)	Composite carbons for methane absorption
Royal Military College (2)	Adsorption of natural gas on porous carbons
Royal Military College (3)	Solid absorbents for natural gas for automotive use
Royal Military College (5)	Absorption of methane by composite carbons
Transport Canada (1)	Safety of natural gas as a ground transportation fuel
Transport Canada 92)	Safety of natural gas fuelled vehicles
University of B.C. (4)	Dual fuelling of a diesel engine with natural gas
University of B.C. (6)	Natural gas fuelling of a prechamber diesel
University of Calgary (1)	Dual fuel engine combustion
University of Calgary (3)	Natural gas for diesel engines
University of Calgary (4)	Combustion in the dual fuel engine
University of Calgary (5)	Dual fuelling of a diesel engine with variable gas composition
University of Calgary (7)	Dual fuelling of diesel engines
University of Calgary (8)	Dual fuelling of a diesel engine with liquid fuels added to the intake

TABLE 2.4: Alternative Fuels for Diesel Engines (continued)

ORGANIZATION	PROJECT TITLE
Methanol	
Ont. Min. Transport & Comm. (2)	Development and testing of large methanol engines
Ontario Res. Foundation (5)	Safety of methanol use in transportation
Ontario Res. Foundation (8)	Performance and emissions of a methanol fuelled compression ignition engines
Royal Military College (8)	Ignition delay
Ethanol	
Ontario Res. Foundation (6)	Performance of a farm tractor fuelled with methanol
Propane/LPG	
Esso Petroleum Canada (1)	Effect of diesel fuel composition on performance
Esso Petroleum Canada (2)	Light hydrocarbons as alternative transportation fuels
Ont. Min. Transport & Comm. (3)	Development and optimization of Dereco propane and natural gas engines
Ont. Min. Transport & Comm. (6)	ICG propane truck demonstration
Ont. Min. Transport & Comm. (7)	OC Transpo propane bus demonstration
Space Fuel Products Ltd.	Dual fuelling of a diesel engine with propane and natural gas
University of Calgary (2)	Dual fuel engine combustion
University of Calgary (6)	Methane and propane for spark ignition engines
University of Toronto (1)	Performance of a diesel engine with direct injection of propane
University of Toronto (5)	Combustion characteristics of propane directly injected into diesel engines
Hydrogen	
Chemetics International Co. (3)	Hydrogen safety
Concordia University (1)	Injection & ignition of hydrogen in compress. ignition engines
Concordia University (2)	Injection & ignition of natural gas in diesel engines
National Research Council (8)	Hydrogen as a diesel fuel
University of Calgary (1)	Dual fuel engine combustion
Universtiy of Toronto (5)	Direct injection hydrogen into a C.I. engine with glow plug ignition
Ammonia	
Chemetics International Co. (2)	Ammonia fuel
Manitoba Research Council (9)	Ammonia fuelled engine
Oxygen with Gasoline	
National Research Council (9)	Fuel analysis
Oxygen with Diesel	
Royal Military College (8)	Ignition delay
Other Fuels	
Bombardier Inc. (2)	Operation of low cetane diesel fuel
Ontario Res. Foundation (7)	Performance of a farm tractor fuelled with canola ethyl monoester blends
University of Saskatchewan	Canola oil as fuel for farm diesel engines
University of Waterloo	Atomization of liquid fuels

3.0 GAS TURBINE FUELS

3.1 Introduction

The high price of fuel which existed in the late 1970's, plus the realisation that supplies of good quality cheap fuels were diminishing, brought about a world-wide interest in seeking alternative fuels. Primary candidates for aircraft jet engine fuels were those derived from coal, oil-shales, and tar sands. With the recent fall in fuel prices and the increase in production of conventional fuels, the interest in carrying out research on fuel effects has waned. Presently, very little work is being carried out. Consequently, these notes will emphasize what has recently been accomplished, rather than what is currently being undertaken. An excellent review of the situation up to 1982 is given in an AGARD* report [Whyte, R.B., 1982], and the following brief notes will be based upon this report, with updating wherever possible.

The thrust for industrial gas turbines has been somewhat different. Instead of alleviating possible fuel shortages, the introduction of alternative fuels has been to reduce energy costs by using (generally) gaseous fuels of low calorific content which become available as by-products of some manufacturing process. Alternative liquid fuels have generally been introduced to save fuel costs, and usually these are the heavier fuel oils. The direct burning of solid fuels has also been considered and, to date, there is considerable interest in the burning of coal-oil or coal-water slurries and in the application of fluidized beds to gas turbines for the burning of a wide range of solid fuels.

3.2 Factors Influencing the Introduction of Alternative Fuels

1. Despite the recent reduction of fuel prices and the ready availability of petroleum-derived fuels, it is obvious that in the long term, as the quality oils diminish, (and, therefore, increase in price) their replacement by heavy crudes, coal, tar sands, and oil shales will accelerate.

2. Fuels derived from these sources are hydrogen deficient and will require considerable upgrading for use in aircraft gas turbines.

3. The trend in commercial road transport is to increase the use of diesel fuel. This could result in a lessening of the refinery cut used for aviation purposes plus a decrease in the demand for the gasoline fraction.

4. If less reforming is done for the gasoline fraction, the by-product hydrogen will not be available for upgrading the crudes to paraffin/diesel stock. A new, cheap supply of hydrogen will be required. In Canada the possibility of

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* Advisory Group for Aerospace Research and Development.

hydro-electric sources to provide hydrogen should not be overlooked since, currently, the hydro-generating power production is not fully utilized.

5. It is anticipated that the new stock will contain increased amounts of sulphur products. The necessary treatment in the refinery will increase the demand for hydrogen thereby reducing the quantity available for aromatic saturation. The possibility of hydrogen supplies for Canada is as above [item 4].

6. Alternative fuels (e.g. alcohols) are a possibility for other transport purposes, but aircraft will continue to be dependent upon liquid hydrocarbon fuels for at least the next fifty years.

7. The requirement for industrial gas turbines to burn alternative fuels increases daily. This is partly due to non-availability of quality fuels but mostly by the demand to use low cost heavy liquid fuels or natural gas, or to utilize by-product fuels (often low calorific gases) in order to save energy and/or to reduce atmospheric pollution. The variation of fuels for industrial gas turbines is much wider than for aircraft gas turbines. However, the former are more easily modified so as to overcome any possible effects due to combustion phenomena, corrosion, etc.

3.3 Typical Fuel Properties

Because of the very wide range, a comprehensive listing of fuel properties is not possible here. Tables 3.1, 3.2 and 3.3 give some typical fuel values. For a more extensive coverage the reader is referred to [Odgers, J., et al., 1986]

3.4 Effects of Alternative Fuels Upon Engines and Fuel Systems

3.4.1 Combustor heat transfer

(a) Solid Fuel Firing

In general, the burning time of a particle of coal will be about ten times that of a liquid fuel droplet having the same diameter. Thus, for the same residence time (i.e. same combustor volume) the coal particle diameter will have to be about 1/3 that of the droplet (say about 5 to 15 μm for coal). In addition, there are problems due to slag formulation and the amount of sulphur usually found in the coal. Since the particles will have an emissivity approaching unity, the flame radiation is considerably higher than the corresponding liquid flame at the same temperature. Hence, wall temperatures can become a severe problem. The difficulty may be overcome to some degree by the use of oil or water-slurries [Foster, C.B., 1977 and Demeter, J.J., et al., 1977]. Due to such problems, indirect firing is preferred; a system which can also use wood and sawdust as fuels, and even has potential for certain incineration processes [Strumpf, H.J., 1979 and Mills, R.G., et al., 1980]. An alternative to either of the above techniques is to use a pressurized fluidized bed [Whyte, R.B., 1982].

Fuel	% MASS					Volatile	Ash	Gross Cv MJ/kg	Stoic. A/F mass	Bulk kg/m^{-3}
	C	H	N	S	O					
Wood (Typical)	52.2	6.1	0.1	-	41.6	79.3	1.5	20.88	5.0	850
Peat	58.0	5.9	2.0	0.4	33.7	74.8	11.1	23.41	5.4	900
Lignite	72.0	5.2	1.3	0.9	20.6	49.6	12.4	29.00	7.1	500
COALS										
Sub-bituminous	72.5	4.8	1.5	4.0	17.2	47.5	17.5	28.97	7.3	700
Bituminous	85.0	5.6	1.5	1.4	6.5	36.7	7.0	35.82	7.8	700
Coking Steam	91.6	4.5	1.4	0.7	1.8	18.0	8.0	36.75	10.1	700
Semi-Anthracite	89.7	5.6	0.6	0.9	3.2	12.9	17.4	35.87	10.1	750
Anthracite	94.4	2.9	1.1	0.7	0.9	5.0	8.0	35.82	9.8	800
Coke	93.0	3.0	1.0	1.0	2.0	8.0	7.0	34.33	9.6	700

TABLE 3.1: Some Properties of Typical Solid Fuels

Fuel	% MASS C	H	S	MW g/mol	DISTILLATION IBP K	TAV K	FBP K	Rec %	Net CV MJ/kg	Stoic. A/F mass	Density kg/m^{-3}
100/130 Octane	84.72	15.23	0.05	99	313	372	435	98	48.39	15.61	723
80 Octane	86.00	13.59	0.27	104	315	383	453	97	43.43	14.58	737
Wide Cut	85.48	14.27	0.25	142	330	446	510	98	43.19	14.77	761
Aviat. Kerosine	86.04	13.91	0.05	160	423	472	533	99	43.19	14.72	799
High Flash Ker.	86.39	13.42	0.19	167	457	490	533	99	42.94	14.57	823
Gas Oil	85.70	13.53	1.34	204	454	531	640	98	42.83	14.56	827
Med. Diesel	85.55	13.60	0.85	208	456	538	616	96	42.43	14.55	836
Marine Diesel	85.21	13.13	1.66	256	464	-	crack	90	42.38	14.41	870
Light Fuel Oil	85.06	11.36	3.68	360	459	-	crack	50	40.91	13.86	921
Med. Fuel Oil	84.76	11.23	3.99	410	483	-	crack	46	40.59	13.80	939
Heavy Fuel Oil	84.98	10.85	4.15	450	503	-	crack	25	40.43	13.69	952
JP-4 Synthetic	85.65	14.30	0.05	115	385	430	449	99	43.12	14.62	775
Kerosine Synth.	86.65	13.30	0.05	195	491	518	591	98	42.88	14.58	846

TABLE 3.2: Some Properties of Typical Liquid Fuels

GAS	H_2	CO	CH_4	C_3H_8	Natural Gas Sweet (A)	Natural Gas Sweet (B)	Natural Gas Sour	Prod. Gas	Blast Furnace Gas
Composition (Vol %)									
CH_4			100		73.1	95.2	58.7	1.2	0.5
C_2H_6					23.8	3.7	16.5	-	-
C_3H_8				100	-	1.0	9.9	-	-
C_4H_{10}							5.0	-	-
C_6H_{12}							3.5	-	-
H_2	100							16.5	3.0
CO		100						24.0	27.5
CO_2								7.5	10.0
O_2								0.6	1.0
N_2								50.1	58.0
Usual Impurity % Volume					0.3	0.2	6.4	0.1	4.0
Mean Molecular Weight	2.02	28.0	16.4	44.1	19.76	16.98	26.8	24.9	28.8
Net CV @ 100 kP & 298 K									
MJ/kg	119.7	10.1	50.01	46.35	46.93	49.85	45.07	4.76	3.09
MJ/normal m^3	10.64	12.45	35.29	89.92	40.82	43.36	53.10	5.20	3.92
Stoichiometric									
A/F (vol)	2.38	2.38	9.52	23.80	10.95	10.02	14.20	1.06	0.726
A/F (mass)	34.2	2.46	17.21	15.65	16.06	15.52	13.20	1.24	0.731
Flammability Limits @ 1 atm & 298 K									
0_{week}	0.12	0.39	0.53	0.58	0.54	0.53	0.55	0.70	-
0_{rich}	6.1	6.1	1.58	2.5	1.81	1.70	2.1	-	-

TABLE 3.3: Some Properties of Typical Gaseous Fuels

(b) Liquid Fuel Firing

The prediction of changes in wall temperatures due to the use of alternative fuels may be fairly well accomplished using long-established and simple correlations [Whyte, R.B., 1982 and Kretschmer, D., et al., 1978]. Possible exceptions are for the newer combustors employing weak mixtures (and simulating pre-mixed conditions) in the primary zone. For such combustors the predictions are conservative. New and complex prediction techniques do not appear to have accomplished a better accuracy in general, although such techniques (after suitable 'calibration') can indicate local effects which are impossible to predict with the older correlations. For conventional combustors, a decrease in the hydrogen content of the fuel will result in an increase of wall temperatures within the combustor [Whyte, R.B., 1982; Odgers, J., 1980; Gleason, C.C. et al., 1979; Gleason, C.C. et al., 1979; Jackson, T.A. 1980], largely due to the increase in flame emissivity which increases radiation heat transfer to the walls [Marsland, J. et al., 1969; Beér, J.M. et al., 1972; Blazowski, W.S., 1977]. This is particularly true for engines operating at low and moderate compression ratios. Similar effects have been noted for industrial gas turbines [Beauserman, G.W. et al., 1980; Singh, P.O. et al., 1980]. A reduction of hydrogen content, from 14.5% (typical good quality kerosine) to 13%, can reduce the life of an aircraft engine by as much as 50%. For high compression ratio engines, the operating conditions ensure a flame emissivity approaching unity and effects due to hydrogen content are less obvious. Also, for systems employing premix or pseudo-premix (e.g. efficient air-blast systems) the effects are greatly reduced [Gleason, C.C. et al., 1979; Gleason, C.C. et al., 1979]. It is necessary that heat transfer correlations be updated to include modern lean-primary zone combustors. Continuing work is required to improve the design of film-cooling components such that they can offset the effects of fuels having reduced hydrogen content.

(c) Gas Fired Combustors

High calorific fuels such as natural gas and propane behave in a similar fashion to liquid hydrocarbons, from the viewpoint of wall temperatures. However, gases having a low calorific content may give rise to increased wall temperatures (at the same gas temperature) due to the reduction of the cooling air available. The effects may be noted throughout the combustion chamber but they are more likely to be found in the primary zone, since the rapid diffusion of the gases often gives rise to an increased primary zone efficiency compared to liquid fuels.

3.4.2 Exhaust carbon content (all systems)

In a broad sense, hydrogen content is the largest factor influencing exhaust carbon (smoke) when alternative fuels are considered [Whyte, R.B., 1980; Odgers, J. et al., 1986; Gleason, C.C. et al., 1979; Gleason, C.C. et al., 1979; Gleason, C.C. et al., 1980; Blazowski, W.S., 1977]. A smoke emissions correlation has been suggested which enables the effect of fuel changes to be predicted with fair confidence [Odgers, J. et al., 1982 and Kretschmer, D. et al., 1987]. Recent work has suggested that it may be possible to improve this correlation by adding

terms which will predict the secondary effects of physical and chemical structures. In particular, this may be required to cater to effects due to fuels having high naphthalene content. It is desirable that a standard technique be adopted for the determination of exhaust carbon. The most accurate technique would probably be some form of gravimetric determination following the extraction of an isokinetic sample.

3.4.3 Gaseous emissions

(a) Gaseous Fuels

If the fuel gases have a high energy content, the amounts of hydrocarbons and carbon monoxide found in the exhaust are generally smaller than for the same energy release using liquid fuels. However, low calorific gases can give rise to increased emissions due to:

(i) the increase in the total mass flow within the primary zone, which effectively reduces the residence time;

(ii) the effects of the inert content of the fuel gases upon the reaction rate.

The amounts of thermal NOx may also show an increase for some of the low calorific gases since, oddly enough, they often have higher flame temperature due to the reduced quantities of air required for combustion. The problems associated with fuel-bound NO_x are identical to those of the liquid fired combustors:

(b) Liquid Fuels

The initial studies [Whyte, R.B., 1982; Gleason C.C. et al., 1979; Jackson, T.A., et al., 1980; Blazowski, W.S., 1977; Bauserman, G.W., et al., 1980; Singh, P.O., et al. 1980] indicated that gaseous emissions (H/C, CO and thermal NO_x) and combustion efficiency show only a small dependence upon the various fuel properties. This is still considered to be true for both aircraft and industrial combustors at conditions of full load or any other condition having high inlet temperatures and pressures. However, recent studies (as yet unreported) at atmospheric conditions (approximating engine idling) have shown some secondary effects due to fuel type, both in terms of physical and chemical structure. The full analysis of these effects is not yet complete. If the chemical structure effects are confirmed, this could have a considerable impact on those chemical models which currently ignore any possible differences upon combustion due to fuel type. For Simplex atomizers and other pressure-jet types, changes to droplet size, due to the physical properties of the fuels, have been shown to be significant to the production of exhaust pollutants and to the reduction of combustion efficiency. For the same atomizer, a decrease in hydrogen yields a larger droplet and, hence, increased pollutants and decreased combustion efficiency. Some of the heavier liquid fuels contain nitrogen compounds as an impurity. Experiments have shown that, with conventional industrial systems, a considerable fraction of such compounds is oxidized to form NO_x in addition to that formed

thermally. Such NO_x from 'bound nitrogen' cannot be reduced by conventional methods, such as steam/water addition, or by exhaust recirculation. Nor is it reduced by weak mixture burning. Two techniques have been investigated:

(i) the rich-lean system

(ii) the use of a catalyst.

In the first system, the gas is burned as a rich mixture; during this process the nitrogen components are destroyed without the formation of NO_x. (Basically the reaction temperatures are lowered and the fuel is apparently more competitive for the available oxygen). Next, dilution is attempted such that mixing is near instantaneous; the mixture is caused to burn at weak conditions (ideally without passing through stoichiometric), thereby minimizing thermal NO_x. For proprietary reasons neither of the systems is well documented.

The amount of sulphur in the fuel is often substantially increased for the heavier fuels. Almost all of this appears as SO_x and there appears to be no possibility of combustion control. The sulphur must either be removed at the refinery or the SO_x extracted from the exhaust at the stack. There are reports that even with low sulphur fuels, combustion within a gas turbine can give rise to an increased fraction of SO_3 compared with other systems. The resulting increase in the acid dew-point can give rise to serious corrosion within the stack. For the non-distillate fuels there are sometimes ash problems. These may generally be minimized by treatment with water extraction and/or salt exchange processes prior to combustion.

3.4.4 Solid fuels

The solid fuel problems generally resemble those of liquid fuels. For 'conventional' solid fuel combustion in gas turbines the treatments are also similar. A form of combustor, which offers interesting possibilities for pollution control of solid fuels, is the pressurized fluidized bed (PFB) [Nutkis, M.S., 1979; Moskowitz, S. et al., 1978]. A typical PFB uses sand, limestone, or dolomite as the bed material; the fuel (coal, 3-5 mm particles) represents a maximum of 2% of the bed weight. Temperatures are kept at about 1100 K by using a heat exchanger buried in the bed. Fluidization velocities range from about 0.5 to 1.5 m/s and pressures from 0.5 to 1.5 MPa. NO_x formation is minimized due to the low reaction (bed) temperatures and, with the use of dolomite, almost all the oxides of sulphur are removed as sulphate. It is claimed that the system is economically competitive. The major obstacle seems to be the removal of fly-ash from the exhaust gases prior to the turbine. Currently, attempts are being made to develop an electrostatic precipitator capable of operating at exhaust temperatures and pressures.

3.4.5 Atomization and evaporation

For any given injector, the physical properties of a fuel which effect atomization are viscosity, surface tension, and density.

Of these, viscosity is generally acknowledged as being predominant because of its large variation as fuel molecular weight (density) increases [Whyte, R.B., 1982; Odgers, J. et al., 1986]. Since the evaporation time for a droplet is a function of its diameter raised to some power (n≈2), it follows that the same factors which influence droplet size will also influence evaporation. In addition, the evaporation of droplets is influenced considerably by the volatility of the fuel.

If viscosity effects may be neglected (e.g. by changing the atomizer orifice), then the evaporation time for droplet combustion is far less sensitive to fuel type (assuming kerosine requires unit time, then high octane fuel = 0.6 and diesel fuel = 1.2). The use of non-distillates increases the comparative time to 5 or, if droplet size cannot be assumed constant, these latter fuels may require 10 to 20 times longer than kerosine.

Advanced injectors of the air-assist or air-blast types provide better atomization and fuel property insensitivity compared with pressure jet atomizers.

Prediction of droplet evaporation times is not good and areas requiring further investigation include:

(a) effects of cloud burning (is it controlled by envelope or wake evaporation/burning?);

(b) a study of possible liquid phase reactions in non-distillate fuels;

(c) studies of droplet evaporation processes at high pressures, especially at critical and super-critical conditions.

3.4.6 Ignition

For fully premixed systems, the effect of changing fuels may be estimated fairly well and it seems possible that this type of correlation might be extended to gaseous diffusion flames. Effects due to changing liquid fuels are profound and, to date, no prediction technique has been shown to be satisfactory. Certain empirical techniques are suggested in the literature but the accuracy of prediction is low (errors of 40% are common even when a base-line has been established for a particular combustor). A major difficulty preventing prediction is the failure of workers in the field to establish a standard technique for the determination of ignition limits. If minimum spark energy is to be predicted, then a knowledge of the applied/liberated spark energy will be required. It is considered that modelling the ignition process is the most difficult task in combustor modelling. Ignition of solid fuels is generally accomplished using an established gaseous or liquid fuel-fired flame, and then reducing the 'pilot' as the solid begins to burn.

3.4.7 Weak extinction and blow-out

Liquid Fuels

The mechanisms of flame extinction are similar to those of ignition except that there are no spark plug complications such as the amount of energy liberated from the plug or effects due to the plug position relative to the fuel spray [Whyte, R.B., 1982; Odgers, J. et al., 1986; Gleason C.C. et al., 1979; Sampath, P. et al., 1986; Odgers, J. et al., 1983]. Because of this, the models developed for liquid fuels are somewhat better able to predict the effects of changes in fuel upon weak extinction and/or blow-out. Droplet size and volatility again play a major role, with chemical structure only yielding small secondary effects.

For gaseous fuels, limits may often be predicted using the Le Chatelier technique. Recently however, for gaseous weak limit prediction, a new correlation [Odgers, J. et al., 1985; Halpin, J. et al., 1985] has been established which has about the same predictive accuracy as Le Chatelier but is much more widely applicable in terms of inlet temperature effects and mixture compositions, as well as indicating possible limitations due to combustor size.

3.4.8 Fuel thermal stability

Thermal stressing of the fuel and long storage can bring about a degradation of the fuel resulting in the formation of insoluble deposits in engine lines and filters [Whyte, R.B., 1982; Odgers, J. et al., 1986; Giovanetti, A.J. et al., 1986]. High pressure ratio engines and supersonic aircraft are particularly sensitive to these phenomena due to their inherent high thermal loadings on the fuel. Partial blockage of the atomizer can result in temperature maldistributions at the turbine entry and may also cause ignition difficulties. Deposition in the fuel lines can also shorten engine life due to reduced cooling capacity, which in turn may produce bearing failures, etc.

A major requirement in this field is a laboratory test which may be considered to be representative of real engine conditions. Existing test methods are really only of a comparative nature. Refineries are seeking process controls to eliminate the trace components which bring about this degradation, and engine manufacturers are seeking fuel systems which are more tolerant of the effects.

3.4.9 Fuel flow characteristics

Some alternative fuels may have a higher freezing point than existing fuels [Whyte, R.B., 1982], with the result that in-flight problems may be associated with flow behaviour and pumpability. Experiments have shown that certain long range commercial aircraft may experience tank temperatures as low as -43°C during flight. Allowing a 3° margin of safety, this demands a fuel having a freezing point of not higher than -46°C. Considerable experience (e.g. by all US civil carriers flying Atlantic routes) has, however, shown that -40°C

specification fuel [Jet A] is adequate, although a few altitude reductions have been reported. Fuels with freezing points higher than this could well demand in-flight manoeuvres or tank heating in order to prevent pumping problems. The effect is even more likely for certain long distance military aircraft. Recent studies have examined the pumpability within wing tanks and this work should continue. The application of additives for pour-point depression should also be explored, as should research into correlations enabling the prediction of pour-point, freezing point, etc.

Another aspect of fuel properties is their lubricity. Not enough is known about the lubricity of alternative fuels.

A change in vapour pressure could also bring about the possibility of vapour lock, excessive fuel loss at altitude conditions, changes in air release from the fuel, etc. A system of vapour pressure measurement has been developed which simultaneously measures vapour pressure and air release at low vapour volume/liquid volume ratios. Difficulties are experienced with these measurements when the volatility of the fuel is very low, due to the very long periods required to achieve vapour-air release equilibrium.

3.5 Summary

Alternative fuels, based upon tar sands and oil shale derivatives, have been well tested in a number of aircraft combustors. The results indicate that if the atomization equipment is adjusted to give the same droplet characteristics, then the performance of the system suffers little other than from the viewpoint of heat transfer. This latter observation is augmented by an increase in flame radiation due to increased carbon formation. The resultant increase in wall temperatures can reduce the life of the combustor by about 50%. The carbon formation may be largely explained in terms of the hydrogen content of the fuel but secondary effects, due to fuel composition, have also been noted. To offset these phenomena it would be desirable to design future combustors capable of accepting flame emissivities of unity at all operating conditions. The obvious means of doing this is to improve the efficiency of the film cooling devices, or to use protective wall coatings, or to develop ceramic combustors.

The range of fuels for industrial and marine engines is vast and encompasses solid, liquid and gaseous fuels. Solid fuels have not been too successful in gas turbines and the most promising type of combustor would appear to be the pressurized, fluidized bed. This minimizes the air pollution from the viewpoint of NO_x and SO_x but fly-ash is still a problem and exhaust cleaning awaits the development of a suitable electrostatic precipitator. Liquid fuels have the same problems as those outlined for the aircraft engines. Moreover, high sulphur fuels and fuel bound nitrogen may give rise to additional pollution problems. The sulphur may only be treated by removal at the refinery or (after combustion) by absorption within the stack. The possibility of a rich-lean combustor [Whyte, R.B., 1982] offers a means of controlling the NO_x due to both the bound nitrogen and to NO_x produced thermally.

High and medium energy gaseous fuels offer few combustion problems but low calorific fuels may give rise to:

(a) a loss of weak extinction characteristics;

(b) a change in wall temperature distribution, mainly, and an increase in primary wall temperatures;

(c) compressor/turbine mismatch due to the high fuel mass compared with liquid fuels.

Major research problems for all systems are associated with techniques for predicting wall temperature, carbon formation and burn-out. Exhaust carbon may be correlated for any one combustor, at any operating conditions, with any type of fuel, but predictive use of these correlations is limited due to the absence of knowledge of design characteristics which affect the comparative times available for soot formation and burn-out. More research is required in this area. For gaseous fuels, research is required on fuel composition/flame characteristics. There is some concern that gas turbines can give rise to higher ratios of SO_3 to SO_2 concentrations than would occur with other combustion systems. This requires investigation and, additionally, a satisfactory analytical method for SO_3 determination will have to be sought. Present techniques are inadequate and time consuming.

4.0 GASEOUS FUELS FOR SPARK-IGNITION ENGINES

4.1 Introduction

Since Canada has become a net exporter of natural gas and propane, the use of these fuels to reduce the need for oil imports has motivated substantial government support for research and development during the past decade.

In 1980 there were less than 10,000 propane vehicles (0.1% of the total number of vehicles) in the country; there are now in excess of 120,000 (1987). Experience indicates that propane is not only relatively attractive in price (even during this period of lower oil prices) but it can be successfully used in a variety of spark-ignition engines and vehicles. Nevertheless, further research is appropriate because much remains to be done to maximize efficiency, reliability and safety of operation.

Since propane (the primary constituent of liquid petroleum gas) is obtained by separation from natural gas (propane concentration is generally less than 10%), its availability as a prospective transport fuel is much less than that of natural gas. If all of the Canadian propane were diverted for vehicle fuel use, it could supply approximately 10% of the total vehicle fuel need. Thus, other gaseous fuels have been the subject of much development work.

The number of Canadian vehicles now fuelled by natural gas is still only of the order of 13,000 (for both spark-ignition and compression-ignition engines). In 1985, the Canadian Gas Association (CGA) set a target of 150,000 such vehicles in service by 1990, and 3 million by the end of the century. For best efficiency and reliability of natural gas use in engines (and in the associated fuel systems) much research and development activity will be required.

A third alternative gaseous fuel, hydrogen, may be seen as an option for the long term, if and when the costs of hydrocarbon fuels, suitable for vehicle engines substantially exceed the cost of hydrogen produced by hydro-electric or nuclear power. Though the combustion characteristics of hydrogen are attractive, its low density (even in liquid form) and harmful effects on metal properties pose serious problems. These problems must be solved before use of this fuel for transportation applications could become widespread. The on-board dissociation of a carrier such as methanol into H_2 and CO, is a mechanism for using H_2 as a fuel. The most promising use of H_2 in transportation may be as a fuel for fuel cells and in conjunction with electric motors. However, owing to supply and distribution problems, hydrogen appears to have small probability for widespread use as a transportation fuel in the forseeable future.

Early development work on natural gas and propane fuelling of spark-ignition engines has been devoted mainly to the control of fuel-air ratio, gas compression and metering, and to the safety of fuelling and containment. Emphasis has been placed mainly on retrofit of components to engines, which could work either on gasoline or natural

gas, for example. In general, further work must still be carried out to solve these problems.

Dual fuelling of personally-owned vehicles has been accepted as a necessary expedient (until a large network of fuelling stations is established) but this requires costly compromises in performance. For fleet vehicle use of natural gas, it is presently feasible (as it will be later for personally-owned vehicles) to either manufacture or modify engine configurations to use natural gas only. This requires research to optimize combustion over a wide range of operating conditions.

In this Section of the report, we review the characteristic features and problems associated with gaseous fuelling of reciprocating engines and identify specific needs for further research. We begin with a listing of fuel properties.

4.2 Gaseous Fuel Properties

Table 4.1 presents the properties of methane and propane in comparison with gasoline and diesel fuel.

Natural gas consists chiefly of methane which is colourless and odourless. In closed spaces, e.g. coal mines, methane is an explosion hazard. Natural gas which is transported in pipelines is "odorized" with mercaptans to permit leaks to be detected easily.

A potential advantage of methane is its high octane number, which would permit high compression ratio and high thermal efficiency. However, its flame speed or burning velocity at combustion pressure, is relatively low. This means relatively long combustion duration and tends to decrease its thermal efficiency. Propane has a lower octane number and a higher flame speed.

Fuelling with methane instead of gasoline, in the same engine at wide-open throttle, would mean that about 10% less air could be drawn into the engine because of air displacement by the natural gas. This decreases the maximum power by about 10% (at the same compression ratio), and the reduction in flame speed may contribute another 4-5% decrease in power, depending on the engine.

The energy per unit volume of stoichiometric propane-air mixture drawn into the engine is only about 2% less than for gasoline. With relatively high flame speed, the maximum power and efficiency of propane are considerably closer to those of gasoline than to those of methane.

While the fuel storage density of propane is somewhat lower than that of gasoline, the storage density penalty for natural gas is severe. The storage density of methane compressed to 200 atm (3000 psia) is about 0.16 kg/L. Using the figures shown in Table 4.1, this means that a tank with the same internal volume would contain only about 20% of the energy with compressed natural gas than it would with gasoline. A further disadvantage is that a tank designed for 200 atm will be quite massive.

Physical/Chemical Properties	Gasoline	Diesel	Methane	Propane
Chemical Formula	variable	variable	CH_4	C_3H_8
Normal Atmospheric State	liquid	liquid	gas	gas
Boiling Point (Atmospheric Pressure)°C	25-210	150-360	-161.5	-42
Octane Number (Research Octane No.)	90-100	-	130	112
Octane Number (Motor Octane No.)	82-94	-	105	97
Density (kg/L or kg/m^3 for CH_4)	0.72-0.78	0.81-0.85	0.68	0.51
Calorific Value (MJ/L)	32.2	32.9-37.7	-	24.7
Calorific Value (MJ/kg)	42.7-43.5	40.6-44.4	50.0	46.3
Specific Gravity of Vapour (Air=1)	4.25	-	0.55	1.55
Specific Gravity of 0.508 Liquid (Water = 1) 15.5°C	0.73	0.802-0.845	-	
Range of Flammability (% in air, by volume)	0.6-8	0.6-6.5	5-15	2-10
@ 300K P = 1 atm	0.9-4	0.5-2.0	5-14	2-8
Auto Ignition Temperature °C Variable - should specify conditions	257	220	650	470
Latent Heat of Vaporization at boiling point (KJ/kg)	310-502	544-795	510	427
Stoichiometric air/fuel ratio by weight	14.7	14.5	17.2	15.6
Stoichiometric air/fuel ratio by volume	1.87	1.04	9.6	4.0
Sulfur content maximum % by weight (for pipeline sale gas)	0.1	0.55	0.68	.01

TABLE 4.1: Properties of Some Transportation Fuels

Source: J. Heenan, Energy, Mines and Resources, Canada.

The advantage of liquified natural gas (LNG) relative to compressed natural gas (CNG) is that the storage density of the fuel can be increased by a factor of 3 or more, and the fuel storage pressure can be reduced to atmospheric.

One disadvantage of LNG is that it cannot be odorized by conventional methods. Another critical factor is that a very low temperature (-162°C) is necessary to maintain the substance in the liquid state. Also, the gas must be highly purified of contaminants, such as H_2O and CO_2, which may freeze and plug fuel delivery lines. Cryogenic tanks have been developed which will minimize heat leaks and boil off, however the storage period is limited to a few days.

Methane and propane are mild central nervous system depressants and the maximum permissible concentrations in air recommended by the United States Occupational Safety and Health Administration (OSHA) is 1000 ppm (for propane). Methane at 53,000 ppm [5.3% of flammability: Table 4.1] in air becomes an explosive mixture; propane at 24,000 [2.4%].

In the event of a spill, propane gas may collect in drains or other enclosed spaces due to its greater density as a gas. This can be easily resolved by air circulation. It is subject to the hazard known as BLEVE (Boiling Liquid Expanding Vapour Explosion), arising when a tank bursts on heating. This is caused by differential heating of the tank walls. Below the level of the liquid the walls are cooled by the propane. Above the wall there is essentially no cooling; thus the wall is weakened by the heat. Flash vaporization of much of the remaining superheated liquid produces a vapour cloud which may ignite and cause a large detonation, particularly in a large tank.

4.3 Vehicle Performance

The principal drawback of compressed natural gas, compared to gasoline fuelling, is relatively short range, one-fifth or less, with the same volume of tank. The storage pressure of 2400 - 3000 psi (16.5 - 20.7 MPa) roughly maximizes the ratio of gas mass to tank mass. In a typical installation, two steel tanks weighing 250-350 lb (110 - 160 kg), would contain the energy equivalent of about 4.2 imperial gallons (19 L) of gasoline.

Light weight CNG tanks can be made of a steel or aluminum cylindrical shell wrapped with fibre glass or an organic polymer such as Kevlar. Failure of such a tank, due to a crack in the inner shell, will allow the release of gas through the outer containment so that failure may be less explosive than bursting of a solid metal cylinder.

LNG tanks containing the equivalent of about 27 Imperial gallons (125 L) would weigh about 150 lb (68 kg).

In passenger cars, the volume and added weight of the storage tanks for CNG or LNG (allowing for the volume of insulation for the latter) may be a serious penalty. This problem may be reduced somewhat

through proper tank location, and by reducing to a minimum the size of the gasoline tank needed for fuel security.

The relatively massive storage system required for gas fuelled vehicles may adversely affect vehicle handling characteristics so that the storage tank should be located as close as possible to the centre of gravity of the vehicle. The additional braking required is also a consideration.

For dual fuelling, with both gasoline and natural gas, the engine is typically unmodified and compression ratio, valve timing and ignition timing for gasoline and energy may differ considerably from the optimum for natural gas operation. Ignition timing can be modified by an on-board electronic device in accordance with the fuel being used; the other factors cannot. This may seriously affect engine efficiency and (while also allowing for air displacement by the natural gas) maximum power output.

In addition, early versions of conversion kits, used to control fuel-air ratio and spark timing for natural gas operation, have provided inadequate control. Apparently, electronic feedback control is required to obtain best efficiency of operation at all loads and speeds.

With inadequate control of timing and fuel-air ratio, pollutant emissions (e.g. carbon monoxide and unburned hydrocarbons) may well exceed current regulation levels. It is usually accepted that unburned methane is not a grave environmental threat since it is relatively unreactive in the atmosphere. Nitrogen oxide emissions are likely to be a problem, even with the best combustion conditions, so that catalytic reduction will be essential in order to meet NO_x emission standards.

Vehicle operation depends, of course, on fuelling station availability. Each station requires a compressor to raise the natural gas pressure from a few hundred pounds (or less) in the pipeline up to vehicle tank pressure. Compression work may be a small percentage of the heating value of the fuel. Fuelling stations require investments of $200,000 - $300,000, and the compression and metering equipment are often less reliable than existing gasoline systems. This expense could be reduced and reliability improved through research and development. One requirement is for an accurate, reliable, reasonably inexpensive flow meter, which will operate over a wide range of gas pressures and temperatures.

For propane, reliable, fail-safe shut-off mechanisms for fuelling have not yet been developed; thus propane fuelling equipment still requires a licensed attendant. Development work is needed to provide improved fuelling mechanisms for both propane and natural gas.

Natural gas fuelling of vehicles could be much more attractive if reliable, inexpensive small compressors were available for charging cars overnight with natural gas from domestic natural gas mains. Small compressors have been developed but costs are in the range of several thousand dollars; too high for widespread use. In addition, research is

required to ensure that "home" compressors are safe for use by the general population and, that they meet the requirements of local fire marshalls.

4.4 Energy Storage

Work has been done on the study of adsorbent material to provide for increased density of natural gas storage at low pressures. Many materials have been considered including activated carbons, zeolites, clays and phosphates. With activated carbons at pressures of 300 to 400 psi (2000-3000 kPa), the percentage of natural gas adsorbed can be 10 or possibly 15% of the weight of the carbon. Other materials which have been tested include commercial charcoal adsorbent in the form of powdered or granular material. More recently, carbon derived from plastics, such as saran, have been considered. So far, it has not been possible to find a material which provides the same storage capacity at the same cost, weight and volume as with high pressure tanks.

The advantage of natural gas adsorption, in addition to reducing storage pressure, is the possibly of increased safety due to a reduction of the gas release rate after a vehicle accident, or the reduced leakage rates during normal use.

However, problems with adsorbent storage include durability, filling and extraction time, and total usable volume. Contaminants such as water vapour or hydrocarbons could seriously deteriorate the adsorbent capability of certain storage materials. Also, there is the question of whether the odorants present in natural gas would be selectively adsorbed by the material.

Typical comparisons to date indicate that the total weight of storage with adsorbent materials may be double that of compressed gas at high pressure in steel cylinders, which in turn will be approximately double the weight of compressed gas storage in aluminum cylinders wrapped with fiberglass. The volume required for the adsorbent system (with the materials evaluated to date) may be 2-3 times what is required for the high pressure gas tank system.

Work is continuing on the search for new materials.

4.5 Combustion in Spark-Ignition Engines

Liquid petroleum gas and natural gas have quite different combustion characteristics, so the research and development required for best combustion of these fuels (particularly for mono-fuel engines) will have quite a different character.

For propane, as Table 4.1 shows, the octane number is much lower than for methane. But the incidence of knock will depend on fuel composition, equivalence ratio and engine speed. More work is needed on the knock characteristics of both fuels over a range of compression ratios, fuel-air ratios and speeds, as well as over a reasonable variation of fuel composition.

Taking the overall view, the problem of alternative fuels involves many of the most important fundamental problems now facing the development of spark ignition and compression ignition engines for conventional fuels.

4.5.1 Induction

For natural gas, a fuel which burns relatively slowly at engine pressures, increasing turbulence appears as a way to increase flame speed. Further work is necessary to assess the effect of the intake port configuration as well as swirl and squish on the turbulence and flow patterns inside the engine cylinder.

Engine results appear to indicate that the use of swirl generated in the inlet port does significantly reduce cyclic variations. However, there appears to be an optimum; at excessive swirl the volumetric efficiency of the engine typically decreases. Part of this effect is due to excessive heat transfer from the swirling hot mixture to the walls of the combustion chamber. Modelling effort on this subject is in its infancy and more needs to be known about the effects of the swirl on turbulence, heat transfer and flame speed, to prescribe optimum levels and distributions of swirl within the engine cylinder during combustion. Previous studies appear to demonstrate that a single swirl number is inadequate for characterizing the effects of swirl on combustion; the radial distribution of angular momentum is important.

4.5.2 Ignition

Studies of cycle-to-cycle variations in engines indicate that the source of this dispersion is associated with the fluid mechanics of the combustion, principally in the early stages of flame growth. The effects of scale and the intensity of turbulence on cyclic variations require further study.

Concerning reaction kinetics, a substantially better understanding of the elementary reactions that are most important in the ignition process, under various engine conditions, is necessary. Such studies might lead to a better understanding of both ignition and knock.

4.5.3 Flame propagation

The central problem here, on which existing knowledge is still uncertain, is the effect of turbulence on flame speed in pre-mixed gaseous mixtures. It has been assumed for a long time that flame speed increases approximately linearly with turbulence intensity, although data are beginning to appear showing that at high turbulence intensities the flame speed falls off and may even be extinguished. The rate of the increase of flame speed with turbulence intensity appears to be uncertain, at least within a factor of 2. Studies in the past few years have shown that, with fairly intense turbulence, the width of the turbulent burning zone is quite thick, possibly of the order of 10 mm, and that this factor has a strong bearing on the way in which the flame speed is interpreted from pressure measurements during engine combustion. More

needs to be known about the effects of turbulence and chemistry in both lean and rich mixtures.

4.5.4 Emissions

For spark ignition engines, the environmentally serious problem of nitrogen oxide formation is understood in principle but prediction of oxide production rate is limited by uncertainties in temperature levels and temperature gradients within the cylinder during combustion. Also, further study of the mechanisms which convert NO to NO_2 within the cylinder is required. Unburned hydrocarbons may be assisting in this conversion process.

4.5.5 Heat transfer

For spark ignition engines, the effect of heat transfer on knock and hydrocarbon emissions (as well as efficiency) is of importance. Existing heat transfer correlations are fairly primitive and do not take into account the effects of local variations in velocity and turbulence. It is difficult to measure the instantaneous heat flux over a large area of the combustion chamber surface. Certain deposits and cyclic variations complicate the results. Methods do not exist for accurate, economical, three-dimensional modelling of heat transfer in engine cylinders.

In summary, for spark ignition engines, the most important research topics appear to include turbulence and fluid mechanics, combustor modelling, pollutant formation, flame ignition, flame stability and propagation.

4.6 Combustion in Compression-Ignition Engines

For compression-ignition engines, we may classify areas where further research is needed.

4.6.1 Ignition

A serious problem for diesel engines is start ignition at low loads and the prevention of high peak pressures at full load. If direct injection of supercritical natural gas or propane in converted diesel engines is to be realized, the question of spark ignition of sprays may be important. The subject has been studied for continuous flows, e.g. in gas turbines, but little is known of spark ignition of sprays in reciprocating engines. Perhaps glow plug or hot surface ignition is the best solution.

Since compression ignition in open chamber engines is highly dependent on temperature, the kinetics of the compression ignition are important. For alternative gaseous fuels, the understanding of elementary reactions for ignition under engine conditions may lead to better knowledge of both ignition and knock.

4.6.2 Flame propagation

In the diesel engine, flame propagation is greatly assisted by high pressure injection which leads to extremely rapid droplet break-up but, depending on the fuel, vaporization rates may be important. Since the spray is quickly enveloped by the propagating flame, radiation is intensive as the flame consumes the very rich spray. Little fundamental information about flame propagation into very rich mixtures, at high pressures and temperatures, appears to be available. The effect of the radiation on the spray itself is not clearly defined and the extent to which it contributes to very rapid vaporization and the micro-explosion of droplets is not yet known. For the particulate formation process, the flame mechanism and the effects of fuel structure need to be understood.

Deposits on the chamber walls from the combustion process affect the rate of heat transfer and may also influence hydrocarbon emissions.

The effects of swirl and turbulence on the mixing and propagation of flames within diesel combustion need further study and numerical modelling.

4.6.3 Emissions

For diesels and direct injection engines, the problem of particulate emissions may be severe and a solution would require knowledge of both gas phase pyrolysis and particulate formation reactions in rich combustion. Rate data are also needed for particulate oxidation under engine conditions. Currently, the effects of high pressure on the oxidation rate do not appear to be known. There appears to be a major requirement for accurate modelling of the turbulent mixing process in order to determine the optimum mixing rates for maximum particulate oxidation in engines.

4.6.4 Heat transfer

As for spark ignition engines, the relation between combustion events and heat transfer is not well understood. Large cycle-to-cycle variations in both magnitude and timing of the radiative heat fluxes are observed. An accurate estimation of radiation, which is especially important in diesel engines, is difficult because of uncertainty in the distribution and characteristics of the particulates. Simultaneous measurements of temperature, particulate concentration, and radiation flux are necessary to assist in modelling efforts.

For the diesel engine, in addition to the knowledge of the effects of turbulence and fluid mechanics, and of the mechanisms of

pollutant formation as well as flame stability and propagation, more information is needed on chemical kinetics, particle droplet dynamics, and radiation heat transfer and droplet behaviour.

4.7 Safety

In Italy (where there are approximately 200,000 vehicles fuelled with natural gas) it was reported that CNG component failure had not caused any deaths or injuries over a 30 year period. In the United States, CNG fuelled vehicles have travelled over 175 million vehicle miles with only one reported injury in which compressed natural gas was a contributing factor. Of the estimated 1,360 U.S. collisions involving compressed natural gas vehicles, there were no failures or fires involving the natural gas systems; in the 180 rear-end collisions, none of the natural gas fuelled systems failed.

An accident which occurred in the late 1970's did cause damage and injuries. It was caused by an explosion of sour gas carried in a steel tube trailer used to transport untreated natural gas from a well to a pipeline injection station. The untreated gas contained a relatively high proportion of hydrogen sulphide. The subsequent investigation led to the establishment of standards under which gas can be transported in high pressure tube trailers. These limits are much stricter than pipeline quality specifications.

Propane has been a direct cause of two or three accidents in Canada; however investigations revealed that the accidents were the result of poor installation of the system. Had the Canadian Gas Association's (CGA) standards for installations been followed, these accidents could have been avoided.

4.7.1 Corrosion failure of tanks

One current safety concern is a possible hazard due to contaminants in the fuel gas. Tank pressure failure could be caused by corrosion due to the components of the natural gas; the presence of hydrogen sulphide can lead to stress corrosion cracking. This applies to conventional steel tanks; fibre-wound aluminum cylinders, which are considerably less massive, pose a separate set of safety concerns.

Standards exist to control the quality of commercial fuel grade propane, however, corresponding standards for natural gas have not yet been developed. Standards are being prepared based upon the quality of pipeline gas. Relatively small quantities of gas are used in transportation, in relation to industrial and home heating, and the problem has not yet had adequate attention.

The corrosion mechanism of compressed natural gas fuel cylinders appears to be complicated and not entirely understood. Not only does it depend on the concentration of contaminants at pressures considerably higher than are normally encountered in pipeline systems but it may also be dependent upon the cycling of pressure and temperature to which the cylinders are subjected. A variety of metals and alloys are used for these high pressure cylinders and each of these materials may have different corrosion resistant characteristics.

What is required is the scientific information needed to develop the minimum gas quality standards for natural gas to be used as CNG fuel for vehicles. The minimum quality standards should specify the allowable content of the water, carbon dioxide, hydrogen sulphide, total sulphur compounds and any deleterious trace contaminants.

It has been suggested that the hydrogen sulphide problem may be due to hydrogen embrittlement. One way to alleviate this problem is to use aluminum alloys, since aluminum shows minimal susceptibility to hydrogen effects. Hydride-forming metals and alloys should not be used for structural containment with hydrogen containing gases. Containers with thick walls of low strength metals are expected to contain hydrogen more safely than containers fabricated from the same alloys treated for high strength.

When compressed to a maximum pressure of 3600 psi (24 MPa), gas containing hydrogen sulphide, allowable under utility contract specifications, is classified as "sour" by the National Association of Corrosion Engineers (NACE). This means that some fuel containers with inappropriate metal composition may rupture at service pressures. Work on this subject is being performed at B.C. Hydro Research and Development under sub-contract to B.C. Research. In one set of tests the fracture mechanics of double-cantilevered beam specimens are being studied to assess the cracking resistance of the steels used in compressed natural gas storage tanks, in comparison to the known resistance of oil field steels. In a second program, tensile tests will be made to determine the relative behaviour of compressed natural gas cylinder steels and oil field steels in a corrosive environment.

Although a lot of work has been devoted to the problem, the question of the safety of burst discs used in high pressure gas storage tanks is still not finally answered. Further work is continuing.

4.7.2 Engine failure due to line blockage

Blockage of fuel lines could be the result of hydrate formation. If the pressure of natural gas is suddenly reduced from a storage pressure of, say, 2400 psi (160 atm) in a regulator, the temperature drop could approach 50°C. If the regulator freezes, due to ice or hydrate formation, this could cause the engine to stop. Normally this would merely be a matter of inconvenience, but engine failure in traffic could create a hazard, depending on traffic conditions. One way to correct this condition is to use a gas heater or to inject methanol into the gas at the compression stage to absorb the water or to ensure the gas is dry by adding a drier to the compressor station.

4.7.3 Fuel leakage

Safety assessment of compressed natural gas, liquefied natural gas, and liquid petroleum gas, should take into account the possibilities of fire and explosion resulting from fuel leakage from vehicles in normal operation or in crashes.

Small leaks could create an explosion hazard when vehicles are stored in enclosed spaces over a period of days. There may be many possibilities of system leaks and possible accumulations of explosive mixtures; there is a possible need for on-board gas detection alarms and for venting of the passenger compartment.

It has been demonstrated that vents in the roof and fire wall can prevent explosive accumulations of hydrogen or methane in the passenger compartment, if the leakage rates are low. However, high leakage rates might produce combustible concentrations in both vented and non-vented vehicles. An on-board gas detection system may conceivably be needed to assure adequate safety.

An important difference between gasoline-fuelled vehicles and gaseous-fuelled vehicles is that gaseous fuels are typically stored under pressure so that it is more likely that fuel will be lost if a leak should occur.

The sealing of the space immediately outside the fuel (natural gas) storage tank is important, to prevent leaks from the tank entering the rest of the trunk compartment. This method of sealing requires the use of a plastic bag to surround the tank, the contents of the bag being vented to the outside of the vehicle. Further work, to find a plastic which will be durable in low temperatures, has been necessary.

4.8 Research Needs

According to Joyce [1983] the following items are priority research requirements for the use of natural gas in transport vehicles.

1. Standards for gas composition.

   The potential effect of corrosive contaminants such as water and hydrogen sulphide or other sulphur compounds, calls for standards on the quality of gas which may be used as a vehicle fuel.

2. Fuelling stations.

   High efficiency, low cost, reliable and durable compressors are needed for fuelling stations. Additionally, compressors of lower cost are required for home use, to compress natural gas to vehicle storage pressures. Devices need to be developed for low cost, accurate metering of natural gas fuelling and for provision of automatic microprocessor-controlled billing. It would be desirable to find a means whereby the energy and the high pressure gas in the intercity pipelines could be used to offset the fuelling station expenditure of energy and compression.

3. Vehicle fuel system.

   The volume, mass, and safety of the fuel storage system are important considerations calling for further research and

development work. Low pressure storage methods could reduce the mass and allow tanks to be fitted more easily into the shapes of various vehicles. Furthermore, they would reduce the weight penalty and improve vehicle performance. However, there are important safety considerations associated with high pressure gas tanks and it would be desirable to have tanks with reduced pressure, possibly using a new type of absorber material.

Systems are necessary to control fuel-air ratio and spark advance over a wide range of load and speed in order to obtain the best fuelling with natural gas.

4. Engine modifications.

For dual-fuelling engines, ignition systems and fuel-air ratio control, methods must match the compression ratio of the dual-fuel spark ignition engine. For engines with dedicated natural gas, fuel modifications to the engine may include supercharging or turbocharging, optimized ignition systems and spark control devices. Similarly, fundamental research into the characterization of natural gas ignition in "diesel type" engines is required.

5. Research on fundamental properties of natural gas and methane.

More work is needed on ignition, on knock behaviour as a function of speed, on air-fuel ratio and on the effects of turbulence on flame speed, as well as further study on the effects of a variable composition of the natural gas on combustion properties.

6. Safety.

As mentioned earlier, safety concerns are numerous, though there is no reason to doubt that high standards of safety can be engineered, given adequate data.

7. Compatibility with Electronic Fuel Management Systems.

With the modern automobile employing electronic ignition systems interfaced with onboard computer and engine sensors, a need exists to conduct research on conversion kits. The majority of natural gas powered vehicles will continue to be conversions rather than original manufacture, and the hardware in the conversion kit must be capable of adapting to and taking advantage of the on-board sensors and computers. Also, special sensors and metering devices will be necessary for the natural gas. Without this research and development the industry could die a natural death before its time.

There are similar research needs for propane vehicles, though they are not as urgent as those of natural gas. The propane market is

further developed than that of natural gas and some research has been carried out by equipment manufacturers. The question of compatibility of propane hardware with modern electronic fuelling systems is the number one priority. With respect to the fuelling of vehicles, a safe, reliable automatic stop-fill filler system is required. Also, propane direct injection systems for spark-ignition and compression-ignition engines are worthy of study.

For access to a computerized data base for natural gas fuels contact: Ms. J. Boisvert, Natural Gas Information Centre, B.C. Research Council, 3650 Wesbrook Mall, Vancouver, B.C. V6S 2L2, Phone (604)224-4331.

5.0 ALTERNATIVE LIQUID FUELS FOR RECIPROCATING ENGINES

5.1 Introduction

Reciprocating engine-powered vehicles, operating on liquid fuels, comprise the vast majority of the total vehicles used in North America. This position will not change significantly, at least into the early twenty-first century and likely longer. The use of many small vehicles for transportation over significant distances within the North American continent (and other world areas) is an established practice that is expected to continue in the forseeable future. A common fuel supply across the continent, that can satisfy the needs of current vehicles must continue. The introduction (and distribution) of alternative liquid fuels, which will be compatible with current vehicles, can be accommodated in a similar manner as the introduction of unleaded gasoline in the 1970's. The introduction of alternative fuels, which will not be compatible with current vehicles and/or distribution systems is a longer term consideration. The use of vehicles that are capable of operating on one or more types of fuels is an established fact, although this approach is one which is still being evaluated. The operation of dedicated vehicles, with smaller route structures (i.e. urban transportation systems) poses no significant problem in terms of fuel type or availability. In summary, therefore, the development of alternative liquid fuels for ground transportation has to take into consideration current and future engine and fuel system design, distribution system design and availability, as well as the need for intra-continental standardization.

Alternative liquid fuels for reciprocating engines will be used in both spark-ignition and compression-ignition (diesel) engines. The modification of diesel engines, to provide some form of ignition enhancement which will satisfy the lower ignition quality of some alternative fuels, introduces a third class of engine. For the purposes of this report such engines will still be considered compression-ignition or diesel. Fuels of interest are, therefore, the liquids which will replace or partially replace petroleum-derived gasoline and diesel fuel.

Forecasts for the future demand for diesel fuel and gasoline, that were made by the National Energy Board as recently as 1981, show (with pre-recession optimism) a considerable increase in the consumption of gasoline and diesel fuel. Actual demands, in subsequent years, have been much lower because of the recession and because of conservation measures.

The surplus of conventional petroleum crude oil, brought about by world-wide recession, conservation, and OPEC conflicts has had both good and bad effects on programs, started in the 1970's, to make Canada energy self-sufficient. The major disadvantage has been the slow down in the planned expansion of the tar sands bitumen plants that would have allowed for an increase in the availability of synthetic crude, from 10% of total crude supply in 1984 to 24% in 1990 and 49% in 2000. Current synthetic crude production satisfies about 12% of Canadian requirements and planned expansions are on a relatively small scale. An off-setting

advantage is the extension of the time frame in which alternative fuel use would have become necessary to satisfy predicted demands. The value of time gained can best be illustrated by reference to the use of the low level alcohol/gasoline mixtures, which are discussed more fully later in this report. This approach to alcohol use, which was anticipated to bridge the gap between current and purpose-designed vehicles that can operate on neat methanol, may not be extensively needed (except possibly for octane enhancement).

5.2 Alternative Fuels Sources in Canada

5.2.1 Tar sands

Canada has vast reserves of tar sands bitumen, with total in-place oil estimated at 215 x 10^9 m^3, which is over twice the total conventional world oil reserves. Currently, the majority of tar sands bitumen is mined and processed to crude oil at two of the Athabasca deposits near Fort MacMurray in Alberta - Suncor and Syncrude. As already indicated, the expansion of facilities which require a large capital investment has been drastically curtailed. (An approximate break-even point of $22/barrel provides little incentive when petroleum crude oil is priced at $10/barrel.)

In addition to the economic problems of tar sands development, there are technical problems associated with its use because of its high aromatic content, although these problems are not unsolvable. The chemistry of bitumen shows it to be highly cyclic, containing polycyclic aromatic ring structures (with a number of naphthenic ring compounds). This structure has considerable implications for the nature of the refined fuel products compared to conventional petroleum. Sulfur atoms are mainly contained in thiophenic rings and nitrogen is also aromatically bound. Typical properties (taken from [Steere, D.E., et al, 1981]) of an Athabasca bitumen are shown in Table 5.1, together with typical properties of tar sands and conventional Canadian crude.

The volume of tar sands crude boiling in the diesel range is quite high (47%), compared with 31% for the conventional crude. The use of tar sands crude for diesel production is, therefore, a major objective to satisfy future diesel demand. The technical problems already alluded to are the subject of a considerable amount of alternative fuel research in Canada.

D. Steere et al., 1981, comment that because of the highly aromatic nature of the tar sands crude, it would be expected that the naphtha fraction from this crude would make an excellent blending stock for gasoline without further processing. However, they comment further that the properties of straight run naphtha are such that its aromatic content is low (6% compared with 11% for conventional naphtha) and this is reflected in its low octane number (58 compared with 63 for conventional naphtha). This anomaly is associated with the bitumen processing which produces a majority of highly substituted aromatic molecules with boiling points in the diesel, not the gasoline, range. Light molecules from cracking bitumen are produced by opening rings and removing alkyl side chains, and are mainly paraffinic (low octane components). The 70%

TABLE 5.1 Properties of Bitumen and Crudes

	Bitumen	Tar Sands Crude	Conventional Crude
Density (15°) kg/L	0.975	0.865	0.820
Viscosity at 40°C, cS	3000.0	3.0	2.9
Sulphur, wt %	3.8	0.08	0.2
Nitrogen, wt %	0.6	0.03	0.04
Hydrogen, wt %	10.4	12.6	13.6
Pour Point, °C	-	-45.0	-6.0
Distillate Yield, %V			
1 - C5	0	4.0	3.0
C5-195°C	0	18.0	36.0
195-345°C	13.0	47.0	31.0
345°C+	87.0	-	-
345-560°C	-	31.0	18.0
560°C+	-	0	0

paraffin content of the naphtha is difficult to reform for gasoline manufacture. Future tar sands projects would require more hydrogenation to convert middle distillates into the gasoline portion.

5.2.2 Natural gas, coal, peat and biomass

Canada has an abundant supply of natural gas, coal, peat and biomass (forest) resources from which alcohol fuels can be produced. Of predominant interest, methanol has been identified by the Federal Department of Energy, Mines and Resources as a potential component of the transportation pool in Canada. Currently, the most common feedstock for methanol is natural gas, usually produced by steam reforming.

The use of carbonaceous feedstocks requires an additional processing step because the gasification results in a hydrogen-poor synthesis gas. A carbon monoxide shift conversion to produce carbon dioxide and hydrogen is used to enrich this synthesis gas.

Methanol has been considered as a replacement or as a blending material for gasoline because, among other attributes, it has an attractive octane rating. Its properties, and the problems associated with its use, are the subjects of subsequent sections within this report. Ethanol, in a similar manner, has potential and has been used and evaluated for use in spark-ignition engines. The choice is largely one of availability. Production of ethanol by fermentation is much less attractive than production of methanol from natural gas because of high cost, even for large scale production. The production of ethanol for fuel use may be limited to agricultural centres where suitable crops for fermentation are grown.

Additionally, methanol is being evaluated for use in diesel engines as a freely available alternative fuel which has potential for reducing particulate emissions. Legislature to limit particulate emissions has resulted in a major research effort to reduce particulates in diesel exhaust by the use of traps. The problem of trapping (and burning) diesel particulates in a satisfactory and viable manner is proving a difficult one to solve. Methanol has a low cetane number and, hence, poor ignition quality. Its use, therefore, requires some fuel or engine modification. This subject is discussed in more detail later.

In summary it can be stated that, in Canada, the use of methanol as an alternative fuel for spark-ignition and diesel engines is considered to offer a viable solution to any future shortfall in conventional fuel availability.

5.3 Alternative Liquid Fuels

5.3.1 Alternative diesel fuels

Tar Sands, Cracked Gas Oils, Residual Oils

As previously discussed, crude produced from tar sands bitumen contains about 50% middle-distillate-boiling-range material and, as such, is potentially a valuable resource for meeting the diesel demand. The rapid and extensive conversion, in Eastern Canada, from fuel oil to natural gas for domestic heating, and an increased use of natural gas for industrial heating, has made available a supply of cracked gas oil petroleum fractions boiling in the 200-300°C range (plus residual components) for diesel use. The forecast demand for diesel fuel can only be satisfied by utilizing these components and tar sands crude. The problems of low hydrogen content, and the presence of higher molecular weight and polynuclear aromatics in fuels derived from these sources, can be significant. The main problems are related to the ignition characteristics of the fuel and are best illustrated by a description of the ignition process.

(a) Ignition characteristics

An excellent summary of the diesel fuel ignition process and its effect on engine performance is given by Wong and Steere, 1982; the following discussion is based heavily on this reference. In a diesel engine, the air is compressed in the cylinder and fuel is sprayed at higher pressure into the hot compressed air. Some of the fuel droplets are vaporized and react with the oxygen by pre-ignition reactions. These oxidation, exothermic reactions involve free radical branching and will self-accelerate to a point where auto-ignition occurs. The time lag between the start of fuel injection and ignition is called the ignition delay. This is a very important property and determines smoothness of operation, misfiring, smoking, engine knock and thermal efficiency. If the ignition delay is too long, most of the fuel is injected before ignition occurs. This results in a very rapid rate of pressure rise due to the higher combustion rate and high peak pressure after ignition. Audible knock is produced when detonation of the whole

fuel/air mixture occurs. Incomplete combustion occurs if the fuel/air charge becomes cooled by expansion when the ignition delay is exceptionally long and ignition takes place after top dead centre. This reduces thermal efficiency and hence power output and, with more extensive cooling, produces misfire.

Ignition delay can be considered in two parts - a physical and chemical delay. The physical delay is largely associated with engine design, although fuel properties play a role. Physical delay occurs in three stages - atomization of the fuel, vaporization of the fuel droplets and mixing the fuel vapor with air. Good atomization requires high injection pressure, good injector design, optimum fuel viscosity and high cylinder air pressure at the point of injection. The second stage, fuel droplet vaporization, is associated with fuel volatility, the characteristics of the spray and the pressure and temperature in the cylinder. The third stage, mixing of the fuel vapor with the air, depends upon injector and combustion chamber design. The influence of fuel properties, including volatility and viscosity, upon the characteristics of the spray (such as droplet size and distribution) enter into both the second and third stages of physical delay.

The physical and chemical delays are not distinctly separated into two stages and, although ignition only occurs in the vapor phase, oxidation reactions are proceeding in both the liquid and vapor phases. The liquid phase oxidation involves oxygen dissolved in the fuel droplet. In addition, cracking of larger hydrocarbon molecules is also occurring. The chemical delay is, therefore, dependent on the hydrocarbon composition. The compression ratio, intake-air temperature and pressure, and the amount of fuel injected also play a significant part in chemical delay.

The ignition quality of diesel fuels is normally expressed as a cetane number, which is measured in a single cylinder, variable compression ASTM-CFR diesel engine, equipped to measure ignition delay. Comparison is made with reference fuels which are mixtures of cetane, n-$C_{16}H_{34}$ (short ignition delay arbitrarily set at 100) and hepta-methyl-nonane (long ignition delay, arbitrarily set at 15); originally alpha-methyl naphthalene with a 0 cetane number was used. The cetane number of the fuel is the cetane (% vol) in the reference fuel with the same ignition delay.

The hydrocarbon composition of a diesel fuel has a significant effect upon ignition delay, i.e. cetane number. Hydrocarbons, in order of decreasing ignition quality, are: normal paraffins, olefins, naphthenes (cycloparaffins), isoparaffins (branched paraffins) and aromatics. While this order of rating is true, it is really an oversimplification because the complex nature of many diesel fraction molecules cannot be fitted into a single or simple classification.

The highly aromatic nature of tar sands crude and petroleum fractions in the gas oil boiling range, and the polynuclear nature of residual components, do not lend themselves readily to being sources for good cetane fuel. The chemistry of these sources, although they are hydrocarbons, is somewhat different (from the point of view of

composition and structure) to that encountered with good quality conventional crude [Steere, D.E. et al., 1979 and Glavincevski, B et al., 1985]. For this reason, the diesel fuels produced from tar sands crude, for example, can be considered alternative fuels because it is necessary to consider the effect that these structural differences have upon combustion performance and, consequently upon engine operation and reliability.

(b) Cetane quality

The effect of different hydrocarbon types on cetane number has been referenced. A major factor, although not the only one, is that of hydrogen content. Alternative crude sources such as tar sands, shale oil and coal liquids are all hydrogen deficient. Hydrocracking, fragmenting and splitting larger molecules, and increasing hydrogen content, are an essential part of crude oil production from sources such as tar sands. Hydrogenation also plays a further and significant role in the processing of the synthetic crude. Similarly, hydrogenation of the gas oils can be used for upgrading. Theoretically, processing can be used to produce diesel fuels of suitable quality (from the combustion point of view) and, at the same time, meet a specification cetane requirement of 40 minimum. Tar sands crude, up until the past few years, was essentially all processed in refineries by dilution with conventional crude to compensate for the low hydrogen content. More recently, a new refinery and modifications to an existing refinery (both in Edmonton) have provided a capability of processing 100% tar sands crude. This is achieved by increasing hydro-treatment capability. "Conventional" refineries are normally self-sufficient in hydrogen, since hydrogen produced during catalytic reforming is sufficient to meet processing needs. Additional hydrogen, required for the "tar sands designed" refinery, is produced from natural gas and, therefore, there is additional cost, both financially and energy-wise. Therefore, the improvement of cetane numbers costs money and energy. Thus, the alternative to utilizing lower quality diesel fuel to meet demands is an attractive proposition, and one on which considerable research effort is being expended. An estimate [Steere, D.E., et al., 1979] has shown that by dropping the cetane number to 39 the diesel pool would increase by 3%.

In a similar manner, upgrading of residual fuels by hydrocracking is a route that has been taken by some refiners. Again there is a cost, both in capital investment and operation. The possibility of increasing the use of residual fuels in so called Low Heat Rejection Engines, by the use of ceramic engine components, is a subject of considerable research. Ceramic-coated or monolithic valves, designed to reduce the corrosive effects of fuel bound sodium and vanadium, are also of interest.

5.3.2 Diesel fuel specifications - '1990' Diesel Fuel

Current diesel fuel production in Canada meets a minimum cetane number of 40, this being the requirement of the Canadian National Standard produced by the Canadian General Standards Board (CGSB) CAN/CGSB-3.6. The CGSB Middle Distillates Sub-Committee, in the late 1970's, drafted a diesel fuel specification to describe a fuel that was

anticipated to be available in or about the year 1990. It was a specification describing a "degraded" fuel with reduction in cetane number and higher end point, and was believed to represent the quality of the fuel that would be expected with increased use of tar sands and gas oil components. Because of the reduction in forecast demands and the changes made to Canadian refineries, a new "1990" or "Intermediate" fuel was forecast with a cetane number of 37 minimum (Whyte, R.B., et al., 1984). A comparison of the properties of the current standard and the forecast "1990" and "Intermediate Fuel are shown in Table 5.2. Two batches of the "1990" diesel fuel were blended and a smaller batch of the intermediate fuel was produced. These fuels have been used in various engine programs in Canada, the USA and in Europe.

TABLE 5.2: Selected Diesel Fuel Properties

	Present Spec. CAN2-3.6M83	Future Fuels 1990		"Intermediate"
Property	Type B	Proposed	Actual Blend	Actual Blend
Flash Point, °C	40 min	38-42	60	69
Cloud Point, °C	as required	-	-10	-
Pour Point, °C	as required	-	-36	-27
Distillation 90% recovered, °C	360 max.	360-370	354	303
Sulphur % mass	0.7 max.	0.7 max.	0.5	0.4
Carbon Residue (Ramsbottom) on 10% Bottoms, % mass	0.2 max.	0.2 max.	0.2	-
Ignition Quality: Cetane Number	40 min.	34-36	35	38
Hydrogen % mass	-	-	12.2	12.3
Hydrocarbon type % vol. by D1219				
Aromatics	-	-	48.1	40.8
Saturates	-	-	51.2	58.5

5.3.3 Studies relating to future diesel fuels (tar sands derived)

Effect of cetane number on engine performance

Low fuels, including the "1990" diesel fuel have been evaluated in a number of engines by various researchers [Chan, D.Y., 1985; LeGresley, D.M.B., et al. 1983 Menard, L., et al., 1985;

Chan, D.Y., et al., 1986], (see Appendix A for a more extensive list of references). Because of the number of combustion chamber configurations available with diesel engines, extensive engine testing is required to fully establish cetane effects; this work, is therefore, ongoing. Indications at present are that lower cetane fuel, typical of the "1990" fuel, has the following effects on engine performance.

(i) No substantial change in brake and indicated performance characteristics;

(ii) substantially different cylinder pressure characteristics, i.e. increased rate of pressure rise and higher peak pressures;

(iii) increased ignition delay;

(iv) some (unconfirmed) engine damage on a longer (500 hr) run with one engine type.

Although the cylinder pressure characteristics are influenced (essentially as a result of an increase in ignition delay), no serious problems with operation, down to a 34/35 cetane number, have been shown. A series of longer (500 hr) tests is underway to determine the longer term effect on performance, deposits and engine durability.

Operation of railroad diesels on tar sands fuel (CN = 32) has been demonstrated.

Cetane index

Due to the limited availability of the CFR engines used for measuring cetane number, and to the time and cost involved, the use of a calculated cetane number, known as the cetane index, is common practice. The ASTM Method D976, using the mid-boiling point and gravity of the fuel to calculate the cetane index, is a widely accepted specification method. This method overpredicts the cetane number and is not suitable for products containing synthetic fuels. Work is continuing to determine cetane index by calculation from other properties that take into better account aromaticity, which has a significant effect on ignition quality. An alternative calculation has been developed by the CGSB which utilizes aniline point, gravity, boiling range and viscosity. [Steere, D.E., 1984].

The determination of fuel structure using nuclear magnetic resonance (NMR) and gas chromatography/mass spectrometry, has been very useful in alternative diesel fuel studies. The prediction of ignition quality by NMR has been proposed and appears to give very reliable data.

Diesel engine emissions

The present and future Canadian standards for heavy duty vehicles are as follows:

Grams per Brake Horsepower Hour

	Hydrocarbon	NO_x	Particulates
Current	$HC+NO_x$	=16	Smoke Opacity
Future	1.3	6.0	0.6

To meet these very stringent standards current investigations include:

(a) the use of (diesel fuel) additives and substitute diesel fuels;

(b) the use of trap oxidizers to contain and burn off particulates.

The levels of particulates are so restrictive (less than lubricating oil combustion products in the case of the DDA 2-stroke) that the specification requirements will necessitate the use of anti-pollution devices such as those defined above, even with a good quality diesel fuel. With an extension of the fuel end point and the related presence of high molecular weight hydrocarbons associated with predicted alternative hydrocarbon-based diesel fuel quality, the problems of satisfying the regulations will be compounded.

Alcohols as diesel fuels,

The technology required to use methanol in diesel engines is not as advanced as that for spark-ignition engines and the move to alcohol fuels has been inspired mainly by the need to meet the probable new emission requirements. The use of methanol as a diesel fuel or fuel extender is a relatively new area of study and the problems associated with its poor ignition quality are considered difficult to overcome. In addition, as with the tar sand derivatives discussed previously, the variety of diesel engine configurations is so large that any research program has to be extensive.

Some properties of diesel fuel and alcohols are compared in Table 5.3.

The low cetane numbers and high auto-ignition temperatures of alcohols are obvious deterrents to their use in compression ignition engines. Fuel and/or engine modifications are necessary to overcome ignition and other problems. Possible modifications include:

(a) the use of diesel fuel alcohol solutions or emulsions;
(b) the use of ignition improvers;
(c) the use of ignition assist.

TABLE 5.3: Selected Diesel Fuel, Methanol Properties

Property	Diesel Fuel	Ethanol	Methanol
Boiling Range, °C	18-360°C	78	65
Flash Point, °C	40+	21	11
Autoignition Temp °C	200-220	420	460
Viscosity, cSt at 20°C	2-3.5	1.5	0.75
Cetane Number	40 min	<8	<3

Diesel fuel/alcohol mixtures

Methanol and ethanol have a lower solubility in diesel fuel than in gasoline and, are more sensitive to water contamination. To improve the miscibility or to stabilize mixtures, solubility promoters (co-solvents or emulsifying agents) have been tested and can be used. Solubilizing agents, such as the C_9-C_{11} alcohols have been found optimal with respect to solubility promotion and cold temperature behaviour, however, they are required in volumes approximating the alcohol content (for methanol). These types of new fuels cannot be considered interchangeable with hydrocarbon-based diesel fuel and will require adaptation of the engine/fuel system in order to maintain performance. Energy content, ignition quality, viscosity and cold start characteristics are particularly influenced and, unless compensated, will result in deteriorated performance.

Diesel fuel/alcohol emulsions (possibly containing water) appear to offer the best promise, and methanol/diesel/water emulsions have been studied and continue to be studied in Canada. A 5-30% methanol/diesel fuel emulsion, requiring up to 7% emulsifier, has been examined. The use of water in the emulsion, possibly as a means of dissolving a smoke suppressant additive or ignition improver, has also been studied. Cetane numbers ranging from 30 (for the 30% methanol blend without ignition improver) to about 48 were evaluated. The results of the Canadian program show, in principle, that the use of methanol/diesel emulsion offers a possible approach to solving both diesel fuel availability and particulate emission problems.

Ignition improvers

Ignition improvers, normally organic nitrates, are used on occasion to improve the ignition quality of hydrocarbon diesel fuels. The use of fairly massive doses, i.e. 10-20% of ignition improver (compared to, say, 0.2% for conventional diesel fuel), has been proposed and is being studied. Two principal disadvantages are (1) cost and (2) a possible increase in NO_x emissions.

Ignition assist

Spark-assisted ignition or ignition by glow plugs are possible methods by which 100% methanol fuels can be used [Neitz, A., et al. 1979; Bennethum, J.E., 1984].

Problems such as material compatibility, toxicity and fire hazards associated with methanol fuels are discussed more fully in later sections covering gasoline substitutes. However, the flammability hazard is very serious, particularly for handling and storage, with methanol as a diesel substitute rather than a gasoline substitute. All diesel facilities and handling practices are designed for combustible fuels (i.e. Flash Point >100°F), rather than flammable fuels (NFPA Classification).

5.3.4 Alternative spark-ignition fuels

Alternative liquid fuels for spark-ignition engines that have the greatest potential as replacements for automotive gasoline are the oxygenates, i.e. alcohols. These alcohols are essentially methanol, ethanol and higher alcohols with three to six carbon atoms. The higher alcohols are primarily used in gasoline/methanol blends to improve the miscibility, water tolerance and moderate volatility increase.

In Canada, methanol is the alcohol of major interest because feedstocks for its production are available in substantial quantities. In addition to natural gas, which is the current and most likely long term Canadian feedstock, reserves of non-petroleum feedstocks such as coal, wood and biomass are available. Ethanol, apart from its potential as a co-solvent will not be readily or widely available. Production from ethylene is uneconomic because of the continuing and increasing demand for this gas in the petrochemical industry. Countries with surplus plant material containing sugar, starch and lignocelluloses continue to show an interest in ethanol as an alternative fuel. Brazil, where $9 \times 10^6 m^3$/year of ethanol is produced from sugar cane demonstrates a major interest in this type of fuel production. Unless large supplies of non-petroleum ethanol production feedstock become available, the use of ethanol as a gasoline substitute or extender will probably be limited to local rural centres.

Formulation of fuels

Alcohol containing fuels can be divided into two classifications low-level blends; for use in existing vehicles, and high-level blends which would be used in retrofitted or purpose-built vehicles. A third classification, considered to be an extension of the high-level blend, is the fuel alcohols; which contain a minimum of 85% alcohol.

Low level blends

Octane numbers

Oxygenates can be used to extend availability to satisfy gasoline demand and also to increase the octane rating of gasoline. The latter use is of importance because of the phasedown in the use of lead alkyls and anti-knock agents. The lower alcohols exhibit greater resistance to knock and, in mixtures with gasoline, they show greater blending octane values (BOV) than the pure alcohols. Only methanol, ethanol and branched C_3- C_4 - alcohols improve octane rating. The BOV's are dependent on the composition and octane level of the basestock

gasoline in addition to the amount and type of alcohol blended. The primary mechanism by which alcohols such as methanol and ethanol improve knock resistance is believed to be their relatively high evaporative cooling effect and high auto-ignition temperatures [Nicholas, R., 1980]. Alcohols are not anti-knock agents like tetraethyl-lead or manganese (MMT), and the single cylinder CFR engine, used for rating gasolines, is not entirely suitable for alcohol/gasoline blends because of the effect of the high latent heat of evaporation on the temperature of the fuel-air mixture in the engine manifold. The standardized method of measuring gasoline octane number requires heating of the air-fuel mixture to 300°F (149°C). This temperature may be difficult to meet with the evaporative cooling, particularly with methanol. Test equipment has been modified to ensure proper heating [Heilmann, G. et al., 1981]. This, however, eliminates one of the major assets of the alcohol and the laboratory determination may not be representative of conditions in actual engines. Without manifold heating, the motor octane number (MON) gives considerably higher octane ratings for methanol blends. An additional problem with the octane ratings of methanol/gasoline mixtures is that the difference between the research octane number (RON) and the MON is much greater than with gasoline. This difference, called "octane sensitivity", is used as a measure of the extent to which a gasoline is downgraded under severe operating conditions; the higher the sensitivity the poorer the performance. The problems associated with octane measurements, and the significance of MON and RON in relation to road performance, for methanol/gasoline blends, are such that multi-cylinder engine or road tests are the only reliable way of assessing performance.

Because of the problems of measuring octane numbers using the CFR engine, and the dependence upon gasoline composition, actual blending octane values reported in the literature are quite varied. One set of values is given in Table 5.4.

TABLE 5.4: Octane Blending Number of Alcohols (15)

Alcohol		CH_3OH	C_2H_5OH	$(CH_3)_2CHOH$
5% vol.	RON	134	135	122
10% vol.	RON	132	132	120
5% vol.	MON	98	100	96
10% vol.	MON	100	104	96

Baseline gasoline 91.4 RON, 83.3 MON

Solubility and water tolerance

The solubility of methanol in gasoline is limited and is dependent upon gasoline composition and temperature. Methanol has a higher solubility in aromatic hydrocarbons than in paraffins, with

naphthenes and olefins being somewhat intermediate. Increasing temperature will cause an increase in solubility. A further problem of immiscibility is the water tolerance of the gasoline/alcohol mixture which is due to the tendency for methanol to be extracted by adventitious water that may be present in storage or distribution systems. Poor water tolerance can result in the formation of two layers, the upper one hydrocarbon rich and the lower one methanol/water rich. The water tolerance of methanol/gasoline blends is dependent upon the gasoline composition, temperature and methanol content. An acceptable water tolerance is only possible with highly aromatic gasoline and at temperatures above -20°C; lower moderate aromatic gasolines suffer even more stringent restrictions. To overcome these difficulties the better solubility of the higher alcohols in gasoline is utilized. The higher alcohols have a co-solvency effect on the lower alcohols and are used to improve the water tolerance of low level methanol/gasoline blends. Although the C_5- or C_6- alcohols appear to have a better co-solvency, most interest is in the butanols because of cost factors. Blends, currently of interest, contain 5% methanol and 5% co-solvent. Presently, over 600 outlets in Western Canada are marketing a 5% methanol with 3% ethanol blend as a co-solvent. Over 10% alcohol can cause problems with lean burning engines because the lower energy content effectively "leans" the carburetor. Oxygen sensors may be required to provide mixture control to overcome this problem.

Volatility

Methanol and ethanol have very low volatilities in relation to their molecular weight. Methanol, for instance, has a boiling point of 65°C compared with the lowest molecular weight alkane methane, with a boiling point of -161°C. This low volatility is related to hydrogen bonding in the alcohol; the hydrogen bonds are weakened when small amounts of the alcohols are mixed with hydrocarbons and a very significant increase in volatility is obtained.

An increase in Reid Vapour Pressure (RVP) of about 24 kPa is obtained when 5% methanol is added to a 60 kPa RVP gasoline. The further addition of methanol does not cause any further increase in RVP and will drop off as hydrogen bonding is restored. Other properties which are used to express gasoline volatility, such as its distillation characteristics and vapor/liquid ratio at different temperatures and front-end volatility indices, are also affected by the addition of methanol. The practical implication of the increased volatility is the effect on driveability due to vapor lock. This causes poor acceleration, stalling or difficult starting when the engine is warmed up. As an attempt to compensate for the increased volatility, the removal of butane (which is normally added to provide vapor pressure) does not completely solve the problem because the vapor pressure of the butane deficient fuel at low temperatures is reduced to below specification.

Compatibility with materials

The compatibility of metallic and elastomeric material, used in the bulk fuel distribution system and the fuel system of a vehicle, with alcohols even at the levels used in low alcohol blends, has to be

considered. The corrosion of metals is, in general, more severe with alcohols than with hydrocarbons, and the tendency to harden, swell or degrade elastomers may be quite different for alcohol fuels. Of course the effects are increased if separation of water/methanol occurs. The problems associated with incompatibility are essentially design problems and they will diminish as the possibility for the wider use of alcohol fuels becomes more of a reality.

High level blends

High level blends are, by definition, fuels with such high alcohol content that because of the leaning effects they cannot be used in an engine without making adjustments. Levels of 15% methanol and 23% ethanol are considered maximum for most cars, particularly for cold driving. The interest in these fuels in Canada is considered minor.

Fuel alcohols or "Neat" alcohol fuels

Fuel alcohols are defined as those containing a minimum of 85% volume of alcohol. They require re-designed engines and fuel systems to compensate for the difference in their properties compared to gasoline. Engine design for a fuel alcohol vehicle can take advantage of methanol properties such as high knock resistance, broader flammability limits, higher flame speed, lower flame temperature and emissivity. Typical features of a methanol engine, therefore, would include higher compression ratio, leaner burning, higher volumetric efficiency and reduced spark advance – leading to increased power and improved efficiency. Engine tests, even without optimization for methanol operation, have confirmed power and efficiency improvement [Menrad, H.D., et al., 1980]. Methanol properties that can be detrimental to performance require compensation; these are discussed in the following Sections.

Selected liquid fuel characteristics of a typical gasoline and diesel fuel are compared with methanol in Table 5.5.

Composition

The formulation for an alcohol fuel is related to the method of cold starting. The necessity to add volatile components, to produce a flammable air-fuel mixture at low temperatures, could limit the maximum methanol content to 85%. However, if alternative methods of low temperature starting are utilized, such as using a separate starting fuel, higher concentrations of methanol could be used. Problems associated with the volatility and flame visibility of methanol are discussed later. A nomenclature system using M for methanol and E for ethanol followed by a number representing the % alcohol (with gasoline) is widely accepted i.e. M85 = 85% methanol.

Water tolerance

Water tolerance is not such a major problem as it is with low methanol/gasoline blends. The solubility of water in a typical M85 or M90 formulation would exceed the levels of water condensate that might be accepted in a typical distribution system. Excessive absorption of water will, however, lead to a reduction in energy content.

Octane numbers

The problem associated with the laboratory determination of octane number for alcohol/gasoline blends has already been referred to, and the same problem occurs with pure alcohols. Typical octane numbers, measured by modified equipment are:

	RON	MON
MeOH	108.7	88.6
EtOH	108.6	89.7
Isobutanol	106.3	90.4

The relevance of laboratory-determined octane numbers, for the performance of alcohol fuels in multicylinder engines, is in some doubt. For neat alcohols, the number also becomes of less interest because the fuel consists of pure compounds of constant composition, unlike gasoline whose composition is variable.

Volatility

Volatility, as expressed by the RVP at 38°C, is shown in Table 5.5. Both alcohols are seen to be considerably lower in vapour pressure than gasoline. Typical winter and summer gasolines have higher vapour pressures than both alcohols at all temperatures. A cold start limit for winter gasoline of -25°C or less, compared to 5°C for methanol is reported [Menrad, H.D., et al., 1980]. This value has also been established by other researchers.

Methanol has a much greater latent heat of vapourization than gasoline. For a given fuel energy input rate, methanol requires over seven times the heat addition of gasoline for complete vapourization. Consequently, in addition to low temperature starting problems, the warm-up period is extended and acceptable driveability during this period is hard to achieve.

One way to solve this problem is to simulate gasoline volatility by the addition of more volatile compounds, either hydrocarbons or ethers (dimethyl ether, methyl or dimethoxy methane). Fuel volatility is a balance between cold starting/drive away properties and vapor lock or stability properties. Methanol, blended with light hydrocarbons or gasoline, for cold start enhancement, did not exhibit severe vapour locking tendencies in bench tests designed to simulate the CRC road test for vapor lock [Keller, J.L., et al., 1978]. A very volatile fuel, required for starting below -20°C, is subject to rapid "weathering" and this problem can rule out compounds like dimethyl ether (bp -25°C) and C_4 rich, light hydrocarbon fractions.

Availability and cost considerations have mandated that fleet demonstrations use unleaded gasoline as the "primer". Ford has recommended that 15% volume unleaded gasoline be used; the primary reason for this is not driveability but flame luminosity in case of fire. However, they note that cold starting and driveability could also be improved by the gasoline.

Properties	Gasoline	Diesel*	Methanol
Physical Properties			
Specific gravity	0.70 - 0.78	0.80 - 0.88	0.796
Vapour Pressure: kPa at 100°F (Reid)	48 - 102	Negligible	32
Boiling Point (°C)	27 - 227	191 - 357	65
Freezing Point (°C)	Approx. -57.)	-39	-98
Water Solubility:			
Fuel in H_2O	240 ppm	-	-
H_2O in fuel	88 ppm	.05	-
Viscosity at 37°C (m2/sec)	0.37	1.3 - 4.1	0.47
Chemical Properties			
Formula	Mixture of C_4 - C_{12} Hydrocarbons	Mixture of C_{12} - C_{20} Hydrocarbons	CH_3OH
Molecular weight:			32.0
% carbon	85 - 88	88 - 86	37.5
% hydrogen	12 - 15	12 - 14	12.6
% oxygen	Approx. 0	0	49.9
Fuel volume % of Vaporized Stoichiometric Mixture	2.1	-	12.3
Stoichiometric Air-Fuel Ratio (Mass/Mass)	14.2 - 15.1	14.5 - 15.5	6.4
Thermal Properties			
Lower Heating value: KJ/kg	43,930(avg)	41,600(avg)	19,990
MJ/l	32.2 (avg)	34.9 (avg)	15.8
Heat of Vaporization: KJ/kg	Approx. 349	Approx. 350	1176
MJ/l	Approx. 0.26	Approx. 0.30	0.93
Octane Ratings: Research	91 - 105	Not applicable	106 - 108
Pump (R+M)/2	87 - 98	Not applicable	99 to 101
Flammability Limits: (volume % in air)	1.4 - 7.6	0.7 - 5.0	6.7 - 36.0
Cetane Rating	Not applicable	40 (min)	5
Specific Heat, cal/gm, °C	0.48	0.46	0.60
Auto-ignition Temperature (°C)	232 - 482	204 - 260	470
Flash Point (°C)	-43	40 (Min)	11

*Where applicable, based on CGSB CAN2-3.6-M83 Type A diesel fuel.

TABLE 5.5: Selected Liquid Fuel Characteristics

A methanol decomposition unit, which operates on battery charge at start-up, has been demonstrated. The mixture of methanol decomposition gases (CO and H_2) is an excellent starting fuel. Problems still to be solved include the relatively long (40 seconds) transition period before decomposed MeOH can be shut off, and low temperature battery power limitations.

Materials compatibility

The corrosiveness of alcohol fuels may be influenced by H_2O, CO_2 and O_2. CO_2 and O_2 are more soluble in methanol than in water, thus increasing the risk of corrosion.

Purpose-built vehicles and dispensing systems will take into consideration the corrosivity and should have no problems. However, problems are expected with existing or inadequately retrofitted systems. Material incompatibility is expected, or has been experienced, with terne-plated fuel tanks, galvanized piping, magnesium, aluminum and its alloys, and zinc alloys. The reaction of elastomers is varied: viton, polyurethane polyamids, cork gasket materials and glass fiber reinforced polyester are materials that are affected to different degrees by methanol.

Potentially, the major compatibility problem that has been identified is that of severe engine wear. This problem has been observed in engine and vehicle tests. Cylinder bore wear has been especially severe, and in one series of tests [Pefley, R.K. et al., 1980] engine dissembly showed upper cylinder bore wear typical of 160,000 km of gasoline service after 19,000 km of methanol service. Above normal bearing wear was also recorded, possibly because of excessive combustion gas blow by due to increased tolerances. Although mechanisms for the increased bore wear have been proposed some are conflicting. Suggested mechanisms include:

(1) induction of large drops of methanol during a cold start that might damage the lubricating oil film at the upper piston ring;

(2) dissolution and removal of additives from the oil by methanol;

(3) poor lubrication due to slow engine warm-up;

(4) acidic condensates from combustion gases causing corrosion. Acidic materials include formic acid, peroxides and nitrates. The role of formic acid as a precursor of corrosive wear has been questioned.

A reduction in wear can be achieved by using lubricating oils formulated specifically for methanol service. The final solution, however, may require a fully optimized engine design.

Environmental health and safety considerations

Major problems identified with methanol are its high toxicity in combination with low odor intensity, and wide flammability (over a

temperature range typical of ambient) combined with low flame luminosity. Methanol flames are virtually invisible in bright sunlight and, therefore, firefighters and others may be unaware of exposure to potentially toxic concentrations and burn hazards. Flammability properties in Table 5.5 show the wider flammability range of methanol compared to gasoline. The fact that methanol is flammable at temperatures around ambient can be considered a serious hazard. However, the addition of hydrocarbons for cold starting will drastically reduce the temperature range. There is little difference in the hazards due to auto-ignition of methanol and gasoline.

Because of methanol's miscibility with water, foams used to extinguish petroleum fires are less effective with a methanol fire. The water used to produce the foam tends to mix with the methanol and impede bubble formation. Methanol fires can be fought with water; however methanol remains flammable even when diluted with 20% water.

Recent research by Transport Canada [V. Battista, 1986], conducted to assess the safety aspects of alcohol-based automotive fuels, (with regard to flammability and firefighting techniques) involved gasolines, pure methanol and a range of gasoline/alcohol mixtures. Characteristics such as auto-ignition temperature, hot surface ignition (manifold), flammability limits, flame luminosity, and miscibility with water were investigated.

A task force, formed to review the data from the Transport Canada studies, considered that there were no issues with respect to vehicle safety in connection with the use of low level alcohol fuel blends. With the high level methanol fuels, the main vehicle safety issues which could impact on the need for countermeasures related to:

- Fuel tanks

  There is concern regarding the presence of explosive vapors in the fuel tank headspace, and the possible need for some form of spark arrester in the fuel tank filler neck. In addition, it was noted that it was not known how easy it would be to ignite such explosive vapors. Tests to attempt to ignite such vapors within actual fuel tanks are recommended.

- Hot manifolds

  The increased propensity for high level methanol fuels to ignite on hot surfaces, compared with gasoline, suggests that special precautions may be required to minimize fuel leakage associated with hot engine surfaces such as hot manifolds. Further hot manifold tests are recommended on in-service methanol engines.

- Flame visibility

  Tests conducted in a steel tray demonstrated only fair to poor flame visibility for high-level methanol blends, especially

when the gasoline portion is of low aromatic content. However, it is thought that visibility may be improved when the blend burns on typical surfaces such as concrete, grass, or within a vehicle engine compartment.

Exhaust and evaporative emissions

The different chemical composition of the alcohols compared to gasoline will give an entirely different composition of the minor constituents of the exhaust gases. Unburned fuel products will be mainly CO, alcohols and aldehydes; with little or none of the benzene and other aromatics, polyaromatics and olefins found in gasoline exhaust products. The presence of hydrocarbon additions in the fuel will, however, increase the contents of methane and non-methane hydrocarbons in the exhaust.

Formaldehyde formation from unburned methanol is believed to occur mainly at the lower temperature in the cylinder, during the exhaust phase, and in the manifold. Due to the toxicity of formaldehyde this pollutant must be controlled. Recent research [V. Battista, 1986] shows an increase in formaldehyde emissions by 40% over a temperature range of +25°C to -20°C. (Further investigation of the data shows up to 200% increase in formaldehyde emissions in the temperature range.) However, a surprising trend was observed where levels decreased as the temperature was reduced to -10°C, and then increased with temperature reduction to -20°C. The formaldehyde levels range up to 10 times greater for the methanol-fuelled vehicle as compared to the gasoline-fuelled control vehicle. Although there were some variations, both carburetted and fuel injection vehicles exhibited similar trends. Conditions for alkyl nitrite formation may prevail in the exhaust system.

This same research [V. Battista, 1980] noted that vehicles with methanol fuel injection emit much lower total hydrocarbon levels than the gasoline control vehicle. NO_x and CO emissions were also found to be lower. However, carburetted methanol vehicles had roughly the same or slightly higher hydrocarbons than the gasoline control vehicle.

The physical and combustion characteristics of the alcohols will create less nitrogen oxides (NO_x) due to the greater internal cooling (high heat of evaporation) and lower flame temperature. Moreover, the possibility for leaner operation and spark retard (ignition closer to the top dead center) may further lower NO_x levels, even at increased compression ratios which, otherwise, tend to increase NO_x. Practical tests with multicylinder engines, sometimes supported by computer model calculations, have implied these conclusions [Pefley, R. et al., 1984; Menrad, H., et al., 1982].

- Existing emissions standards in Europe and in the United States can be fulfilled for high-compression neat alcohol fuel engines (in the United States with catalytic converters).

- Reduced out-of-engine NO_x emissions are obtained, and the use of EGR is very effective in the further reduction of NO_x.

- Aldehyde emissions are considerably higher than those from gasoline engines but can, if required, be controlled by an oxidation catalyst.

- Unburned fuel (UBF) emissions, in the early part of the cold test cycles, can be higher than from a gasoline engine but comparable or lower over the complete cycle.

- In a given engine, the addition of volatile components to the alcohols helps to control the UBF and CO emissions at cold start and warm-up; improved engine hardware would otherwise be required.

- Cold operation on decomposed methanol (mainly CO and hydrogen) would be very attractive because very low emissions are indicated.

Evaporative emissions can be a serious problem with alcohols, particularly methanol. Current canister traps have been shown to be unable to control the evaporative emissions to meet legislated (US) tests.

5.4 Research and Development Needs

5.4.1 Compression ignition engine fuels

Tar sands cracked gas oils and residual blends

(i) Continued assessment of the effect of reduced cetane number (possibly down to 30) upon performance and durability, taking into account several engine configurations.

(ii) Development of procedures for measuring cetane index, particularly for non-conventional crude derived fuels.

(iii) Research into the relationship between chemical species and ignition delay.

(iv) Research into the influence of chemical species on pollutant formation during combustion, the relationship between particulates and chemical species being of prime interest.

(v) The development of diesel particulate traps.

(vi) Continued research into the use of ceramic components to allow combustion of high ash residuals.

Methanol

(i) Methods of utilizing low cetane methanol in diesel engines.

(ii) Continued investigation into methanol/diesel fuel emulsion combustion.

(iii) Continued investigation into the use of ignition improvers in methanol.

(iv) Determination of the effect of methanol/diesel blends on engine emissions, with emphasis on particulates.

(v) Research into various problems associated with methanol, such as lubricity, lubrication, fire safety and toxicity (see more detailed description under 5.4.2. SI fuels).

5.4.2 Spark-ignition engine fuels

Low-level blends of methanol/gasoline

(i) Establishment of volatility requirements compatible with current standards and current vehicles.

(ii) Development and definition of fuel formulations that ensure good miscibility and water tolerance.

(iii) Corrosion studies to define the effect of alcohol/gasoline mixtures on current materials in engines, engine fuel systems and fuel distribution systems.

(iv) Development of methods that adequately define the knock resistance of alcohol/gasoline mixtures, and that can be related to road performance.

Alcohol fuels

(i) Designing and building vehicles to take advantage of alcohol properties such as high knock resistance, broader flammability limits, higher flame speeds, lower flame temperature and emissivity. The design should also take into account detrimental properties that result in cold start and driveability problems, corrosion and non-metallic component deterioration.

(ii) Investigation into the mechanism of excessive upper cylinder wear.

(iii) Formulation of lubricating oils that perform satisfactorily with methanol fuels.

(iv) Development of formulations containing low molecular weight hydrocarbons or similar low boiling materials, that improve flame luminosity and cold starting/driveability.

(v) Investigation and development of systems to adapt dissociated methanol as a starting fuel.

(vi) Investigation of materials for use in adsorbing evaporative emissions.

(vii) Development of an on-line method for measuring the aldehyde content of exhaust emissions.

(viii) Investigation of problems relating to poor lubricity i.e. pump and injector wear.

(ix) Determination of the ease with which fuel tank headspace vapors can be ignited for various methanol fuel blends.

(x) Evaluation of the visibility on various surfaces.

(ix) Determination of the ignition propensity of methanol fuel blends on a hot manifold.

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6.0 CONCLUSIONS

Regardless of any economic or politically contrived situation, the eventual depletion of conventional fuel resources will result in alternative fuels being required for transport purposes, and this within the not-too-distant future.

This report has outlined the state of Canadian research on alternative fuels for engines. Attention has been drawn to those areas of research (with particular respect to the combustion regime) which continue to pose problems. The inevitability of Canada having to draw upon its own resources for alternative fuels (e.g. methane, tar-sands, heavy oils), stresses the need for the continuation of research, both from the viewpoint of engine performance and possible stringent air quality considerations.

Considerable research has been done in Canada within this field but the compilation of the present data has shown a definite requirement for a forum where existing information could be disseminated and critically analyzed.

Work on gas turbine engines has demonstrated the general behaviour of alternative fuels and their problems. For aircraft engines, the most important areas demanding further research are:

(1) the alleviation of problems due to changes in heat transfer within the combustor;

(2) a better understanding of soot formation and burn-out;

(3) a definition of the phenomena which control the exhaust pollutants at high combustion efficiencies (say 99%+);

(4) the prevention of deleterious effects due to thermal instability of the fuel.

For industrial gas turbines, low BTU gases and solid fuels pose considerable problems to the combustion systems.

The primary needs for research on reciprocating engines powered by gaseous fuels (natural gas or propane) are:

(1) the effects of mixture motion (turbulence, squish and swirl) on combustion duration, efficiency and emissions;

(2) the effect of gas composition on combustion and corrosion;

(3) new methods for fuel/air preparation and ignition;

(4) the improvement of technologies for the efficient control of engine operation;

(5) the development of techniques for high density energy storage;

(6) improvements to the safety of fuel handling.

Methanol and tar sand derivatives are the prime liquid fuel alternatives for both spark and compression engines. The major problem areas which require continued study are:

(1) neat methanol in spark ignition engines - cold starting, emissions, corrosivity, engine lubrication, fuel pump lubricity and safety;

(2) methanol/gasoline mixtures in spark ignition engines - vapour pressure, solubility, water tolerance and corrosivity;

(3) methanol in C.I. engines - corrosivity, engine lubrication, fuel pump lubricity, solubility/stability, ignition characteristics and engine durability;

(4) tar sand fuels in C.I. engines - ignition characteristics, engine durability and emissions (especially particulates).

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APPENDIX A

RESEARCH AND DEVELOPMENT PROJECTS

IN CANADA

ON ALTERNATIVE FUELS FOR TRANSPORTATION

ACOP TASK FORCE ON ALTERNATIVE FUELS
RESEARCH INFORMATION

ORGANIZATION: B.C. RESEARCH COUNCIL (1)

ADDRESS: 3650 WESBROOK MALL
: VANCOUVER, B.C. V6S 2L2
TELEPHONE: (604)224-4331

CONTACT PERSON(S): DR. M. SMITH DR. L. GETTELL MR. C. PERRY

PROJECT TITLE: SAFETY TESTING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS			TANKS-ON-BOARD

OBJECTIVES:
1. To evaluate cylinder burst discs under combinations of heat, pressure and vibration.
2. To evaluate the ability of cylinder mounting brackets, pipes, tubes, hoses and connections, to withstand crash-level deceleration.
3. To test materials that will not fail at low temperatures when used for sealing tank lines and valves.

REPORTS/PUBLICATIONS:
"Reliability of Rupture Disc Pressure Relief Devices and CNG Fuelled Vehicles", B.C. Research Council Report, C0467, 1984.
"The Crashworthiness of CNG Storage Tank Assemblies", B.C. Research Council Report C0469, 1985.
"Evaluation of Currently Available Compressed Natural Gas Conversion Equipment", B.C. Research Council Report, C0233, 1983.
"Low Temperature Durability of Valve Bagging and Gas Barrier Materials for Natural Gas Fuelled Vehicles", B.C. Research Council Report C0742, 1985.

ORGANIZATION: B.C. RESEARCH COUNCIL (2)

ADDRESS: 3650 WESBROOK MALL
: VANCOUVER, B.C. V6S 2L2
TELEPHONE: (604)224-4331

CONTACT PERSON(S): DR. L. GETTEL

PROJECT TITLE: CONVERSION KIT EVALUATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		POWER FUEL CONSUMPTION	

OBJECTIVES:
To assess the performance of conversion kits for adapting spark-ignition engines to dual-fuelling with natural gas.

METHOD:
Seven CNG conversion kits were tested on three vehicles, a Ford F-250 truck, a Chevrolet S-10 truck and a Dodge 600 passenger car. Power, fuel consumption and air/fuel ratio were measured as functions of speed and load.

RESULTS:
All conversion kits produced approximately 20% less power than the unconverted vehicle operating on gasoline. The differences in power and fuel consumption were most pronounced in the Ford, the test vehicle with the largest engine (with the gas flow requirements of the engine closest to the maximum flow rate of the CNG conversion system). This information is being used in second-generation equipment development.

REPORTS/PUBLICATIONS:
"Compressed Natural Gas Conversion Kit Performance Testing", B.C. Research Council Report C0237, 1983.

ORGANIZATION: B.C. RESEARCH COUNCIL (3)

ADDRESS: 3650 WESBROOK MALL
: VANCOUVER, B.C. V6S 2L2

CONTACT PERSON(S): DR. L. GETTEL

TELEPHONE: (604)224-4331

PROJECT TITLE: EFFECT OF SPARK PLUG GAP ON ENGINE PERFORMANCE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	IGN-QUALITY	POWER OPERABILITY FUEL CONSUMPTION	

OBJECTIVES:
1. To investigate the effect of spark plug gap on engine performance with natural gas fuelling.
2. To determine optimum spark advance.

METHOD:
This was investigated on a Chevrolet S-10, 2.8 litre V6 test vehicle, equipped with a high energy ignition system, operating on natural gas. Four spark plug gap sizes (0.75, 1.12, 1.5 and 2.0 mm) were tested both on a chassis dynamometer and over the road.

RESULTS:
For engine speeds up to 4000 RPM there is no difference in output power or fuel consumption for the four spark plug gaps. Above 4000 RPM the power drops off significantly for a gap of 2 mm, due to severe vehicle misfire. The spark plug gap of 1.5 mm offered the best drivability.

REPORTS/PUBLICATIONS:
"The Effect of Spark Plug Gap on The Performance of Compressed Natural Gas Vehicles", B.C. Research Council Report C0236, 1983.
"Optimal Ignition Advance Curve for CNG Vehicles", B.C. Research Council Report C0235, 1984.

ORGANIZATION: B.C. RESEARCH COUNCIL (4)

ADDRESS: 3650 WESBROOK MALL
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CONTACT PERSON(S): DR. L. GETTEL

TELEPHONE: (604)224-4331

PROJECT TITLE: ELECTRONIC DUAL-FUEL DIESEL CONTROL SYSTEM

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		FUEL-CONSUMPTION DUAL FUELLING	

OBJECTIVES:
To develop a dual-fuel control system for a John Deere JD6466T turbo-charged agricultural engine and for a Caterpillar 3208 naturally aspirated truck engine, enabling operation on a combination of natural gas and diesel fuel.

METHOD:
The system employs the dual-fuel principle and features microprocessor control. To maximize the diesel substitution, it was found necessary to vary the pilot diesel quantity dependent on engine speed, engine load and in the case of the turbo-charged engine intake-air temperature. The maximum diesel substitution under steady state conditions was a function of the knock limited output of the engine at high load, and incomplete combustion at light load.

RESULTS TO DATE:
The conversion system developed consists of three main components: a device to control the diesel quantity, a natural gas control valve, and an on-board computer control unit.

REPORTS/PUBLICATIONS:
"Electronic Dual-Fuel Diesel Control Systems" by P.J. O'Sullivan, L.E. Gettel, Proceedings Conf. on Gaseous Fuels for Transport, Vancouver, B.C. Aug. 7-10, 1986.
"Dual Fuel Natural Gas/Diesel Conversion System in Four-Stroke Diesel Engines", B.C. Research Council Report C0894, 1986.

ORGANIZATION: B.C. RESEARCH COUNCIL (5)

CONTACT PERSON(S): DR. L. GETTEL

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PROJECT TITLE: NATURAL GAS STORAGE DENSITY

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS			TANKS-ON-BOARD

OBJECTIVES:
1. To study possibilities of increasing storage density of natural gas on vehicles.
2. To assess design and safety of CNG Tanks.

REPORTS/PUBLICATIONS:
"Enhanced Storage Density", B.C. Research Council Report C0164, 1983.
"Compressed Natural Gas Fuel Containers", B.C. Research Council Report C0234, 1983.

ORGANIZATION: B.C. RESEARCH COUNCIL (6)

CONTACT PERSON(S): DR. L. GETTEL

ADDRESS: 3650 WESBROOK MALL
: VANCOUVER, B.C. V6S 2L2
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PROJECT TITLE: CNG COMPRESSORS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS			REFUELLING

OBJECTIVE:
To assess performance and needs for development of compressors for compressed natural gas.

REPORTS/PUBLICATIONS:
"CNG Compressor Operations", B.C. Research Council Report C0165, 1983.
"Evaluation of CNG Compressors", B.C. Research Council Report C0166, 1983.

ORGANIZATION: BOMBARDIER INC. (1)
DEPT: DIESEL RES. & DEV. DEPT.
CONTACT PERSON(S): M.L. PAYNE R.M. DUNTON

ADDRESS: 1505 DICKSON STREET
: MONTREAL, P.Q. H1N 2H7
TELEPHONE: (514)253-7333 EXT.7466

PROJECT TITLE: DUAL FUELLING OF A DIESEL ENGINE WITH NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROCESS GAS		EMISS-EXHAUST	
SPARK IGNITION	NATURAL GAS		FUEL-CONSUMPTION	
			DUAL-FUELLING	
			LUBRICANTS	
			OPERABILITY	
			DURABILITY	

OBJECTIVES:
1. To develop a spark-ignition conversion of a diesel engine for fuelling by natural gas.
2. To develop a dual-fuel (diesel/natural gas) diesel engine.

METHOD:
Bombardier has commenced research and development work directed to the introduction of natural gas fuelled engine version of their A1C0 251 and B2400 diesel engine families.

RESULTS TO DATE:

POWER	1093	910	HP
RPM	1200	1000	1/MIN
BSFC	7300	7000	BTU/HP-HR
BSCO	2.6	2.0	g/HP-HR
BSHC (NON-METHANE)	0.0	0.0	g/HP-HR

REPORTS/PUBLICATIONS:
M.L. Payne, R.M. Dunton, F.D. Mills, "Natural Gas Burning Engines for Locomotive and Marine Applications", Intl. Conferen on Gaseous Fuels for Transportation, Vancouver, 1986.

ORGANIZATION: BOMBARDIER INC. (2)
DEPT: DIESEL RES. & DEV. DEPT.
CONTACT PERSON(S): MR. D.Y. CHAN
ADDRESS: 1505 DICKSON STREET
: MONTREAL, P.Q. H1N 2H7
TELEPHONE:

PROJECT TITLE: OPERATION ON LOW CETANE DIESEL FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	OTHER		FUEL-CONSUMPTION	
			OPERABILITY	
			DURABILITY	

OBJECTIVES:
1. To investigate the effect of degraded diesel fuels on the performance and operability of medium speed diesel engines.

METHOD:
Seven different fuels were studied: conventional ASTM No.2-D diesel (reference fuel) and various blends with heavy atmospheric gas oil (end point 400xC), conventional Western Canadian crude, tar sands crude, No.2 and 6 heating fuel, including NRC's "1990" diesel fuel. The cetane number of these fuels was between 29.4 and 46.8 and the aromatics between 28.6% and 55.7%. The test engine was a 12 cylinder Bombardier 251 engine (9" bore x 10 1/2" stroke) rated at 250 BHP/cylinder at 1100 RPM. All tests conducted were of basic performance type, with no more than 16 hours of engine operation on each fuel.

In Phase II of the investigation, durability tests were conducted including 500 hour runs with the "1990" diesel fuel and with a 30:70, 2-D:6-D fuel blend.

RESULTS TO DATE:
No major engine operational difficulties were encountered throughout the testing of the degraded fuels. Some combustion

data, however, indicated that possible long term durability shortcomings may exist. In comparison to the reference fuel, the combustion delay was longer for all test fuels, except the No. 2-D diesel having a high final boiling point. High rates of pressure rise, increased specific fuel consumption and high maximum cylinder pressures were also observed.

No durability problems were encountered with the "1990" fuel but accelerated valve wear and accumulation of deposits in the exhaust system occurred during operation with the 2-D:6-D blend. Since North American medium speed diesel engines are designed primarily to consume conventional ASTM No.2-D fuel, this new information will permit engine/combustion system modification to suit a range of future Canadian and world fuel options.

REPORTS/PUBLICATIONS:
"Alternate Fuels for Medium speed Diesel Engines" Phase II Final Report No. ERD/08/85, Denny Chan, Bombardier Inc., March 1985.

ORGANIZATION: CANADIAN NATIONAL RAILWAYS
DEPT: RESEARCH CENTRE
CONTACT PERSON(S): T.R. DUNN

ADDRESS: 3950 HICKMORE AVENUE
: ST. LAURENT, QUE. H4T 1K2
TELEPHONE: (514)343-5536

PROJECT TITLE: OPERATION OF RAILROAD DIESEL ENGINES ON LOWER QUALITY FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV	IGN-QUALITY	LUBRICANTS OPERABILITY	

OBJECTIVES:
To determine whether a blend of 10% bunker oil with diesel fuel could be used successfully in diesel engines.

METHOD:
- On rail tests (long term) of diesel fuel containing 10% bunker oil
- Operation on Suncor Gas Oil Side Stream (Cetane Number = 32)

STATUS:
- 10% bunker oil use trial completed.
- Railways operating on Gas Oil Side Stream.

RESULTS TO DATE:
The findings were:
(1) The upper limit of residual fuel which did not form deposits at idle was 10%.
(2) Locomotive engines could run on such a blend without major modifications.
(3) Piston ring/liner wear was significantly higher.
(4) Lubricating oil with higher reserve alkalinity, 10 TBN or higher, was required.
(5) Changes in the relative prices of Bunker and Diesel meant that there was little or no economic advantage in the use of 10% blends not considering increased maintenance costs.
(6) Selection of bunkers to ensure adequate quality required continuing monitoring refinery by refinery because of changes in crude slate and processing.
The project concluded in 1984.

REFERENCE:
"Locomotive Diesel Fuel - A Direct Application of One of the Fractions from a Tar Sands Plant", by D.R. Jackson, presented to CGSB Petroleum Committee Seminar, Edmonton, Alta., October 1981.

ORGANIZATION: CHEMETICS INTERNATIONAL CO.(1)

CONTACT PERSON(S): MR. R.E. KNOWLTON

ADDRESS: 1818 CORNWALL AVENUE
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TELEPHONE: (604)734-1200

PROJECT TITLE: SAFETY OF NATURAL GAS FOR VEHICLE FUELLING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	HYDROGEN			REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To identify vehicles where the characteristics of hydrogen would enable it to be exploited as a small scale source of energy in the near future.

METHOD:
Appoint a mutually supportive group of sub-contractors to work in specific areas. Areas covered included:- Submarines, surface vessels, mine vehicles, off-road vehicles, road and rail applications, fixed wing and rotating wing aircraft, lighter-than-air craft. Fuel cells, cryogenic uses and fog dispersal.

RESULTS TO DATE:
Final report issued including nine sub-contractor reports.

PUBLICATIONS:
R.E. Knowlton, "New Uses for Hydrogen in Canadian Energy Systems,", IEA Hydrogen Task VII Workshop, June 1985.
R.E. Knowlton, "New Uses of Hydrogen in Canadian Energy Systems," Final Report, July 1985. DSS File No.01SX 31155-2-2665.

ORGANIZATION: CHEMETICS INTERNATIONAL CO.(2)

ADDRESS: 1818 CORNWALL AVENUE
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CONTACT PERSON(S): MR. R.E. KNOWLTON

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PROJECT TITLE: AMMONIA FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	AMMONIA		EMISSIONS EMISS-EXHAUST OPERABILITY	REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To assess the technical feasibility, commercial prospects and safety problems associated with the use of ammonia as a ground transportation fuel.

METHOD:
Identification and evaluation of the technical systems, cost analysis, analysis of codes and safety problems.

RESULTS:
Final report issued covering the above.

PUBLICATIONS:
R.E. Knowlton and H.G. Wright, "Ammonia Vehicle Fuel - Final Report", April 1984, DSS File No. 01SX 31155-1-2707-X.

ORGANIZATION: CHEMETICS INTERNATIONAL CO.(3)

ADDRESS: 1818 CORNWALL AVENUE
: VANCOUVER, B.C. V6J 1C7

CONTACT PERSON(S): MR. R.E. KNOWLTON

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PROJECT TITLE: HYDROGEN SAFETY

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	HYDROGEN			REFUELLING TANKS-ON-BOARD COLLISION OTHER

OBJECTIVES:
To assess the safety of the transit and bulk storage of hydrogen as a compressed gas or as a cryogenic liquid and the retail storage, refuelling and on-vehicle storage of hydrogen as a compressed gas, cryogenic liquid, metallic hydride or as a micro-encapsulated compressed gas.

METHOD:
The method included: identification of safety problems, assessment of potential hazards, analysis of existing codes and standards and formulation of recommendations.

RESULTS:
Final report issued. Follow-up activities include the establishment and operation of the Canadian Hydrogen Safety Committee. The Committee has made presentations at various conferences and is about to issue a "SAFETY GUIDE FOR HYDROGEN".

PUBLICATIONS:
R.E. Knowlton, "Hydrogen Safety, an Assessment of the Safety Problems Associated with the Use of Hydrogen as a Ground Transportation Fuel," March 1983, DSS File No.07SX 31155-1-6622.

ORGANIZATION: CHRYSLER CANADA LTD.

ADDRESS:
:

CONTACT PERSON(S): MR. T. ELLIOT

TELEPHONE:

PROJECT TITLE: S.I. PROPANE ENGINES FOR LIGHT DUTY VEHICLES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
	PROPANE/LPG		COLD START EMISS-EXHAUST EMISS-EVAPORATION FUEL CONSUMPTION DUAL-FUELLING LUBRICANTS OPERABILITY DURABILITY	REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To review light duty propane vehicle technology, identifying opportunities for improvements and defining R and D strategy for optimizing propane engines and fuel system components.

METHOD:
The study addressed the following:- compression ratio, carburation, ignition, valve timing and intake manifolds, engine durability, engine lubrication, fuel storage and handling systems, dual fuel systems, low temperature operation, propane fuel blends, health and safety considerations.

RESULTS TO DATE:
Work continues under a $1.5 million contract jointly funded by EMR, the Ontario Government and Chrysler Canada.

REPORTS/PUBLICATIONS:
"Optimization of Propane Engines for Light Duty Vehicles", Contractors Report to Energy Mines and Resources, Canada.

ORGANIZATION: CNG FUEL SYSTEMS INC. (1)

ADDRESS:
:

CONTACT PERSON(S): MR. STEPHEN CARTER

TELEPHONE:

PROJECT TITLE: FUEL INJECTION SYSTEM FOR NATURAL GAS FUELLING OF SPARK IGNITION ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		COLD START EMISS-EXHAUST FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To develop a computer-controlled remote-metering fuel injection system for natural gas fuelling of spark-ignition engines.

METHOD:
The basic concept is a classical speed-density fuel injection system. The computer's firmware uses an engine - specific "map" to extrapolate actual airflow into the combustion chambers from engine speed, air temperature, and intake manifold pressure. The fuel delivery calculations are compensated for variations in fuel and air temperature and pressure, device and fuel transport lag times and metering valve error.

RESULTS TO DATE:
System in the testing stage.

REPORTS/PUBLICATIONS:
"Natural Gas Conversion System Development", Energy Mines and Resources Canada Report.

ORGANIZATION: CNG FUEL SYSTEMS INC. (2)

ADDRESS:
:

CONTACT PERSON(S): MR. STEPHEN CARTER

TELEPHONE:

PROJECT TITLE: METERING OF NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK-IGNITION	NATURAL GAS	COMPOSITION OTHER		

OBJECTIVES:
To determine an accurate method of measuring natural gas for refuelling.

METHOD:
Gas behaviour under actual and simulated fill conditions was studied to determine an accurate method of measuring compressed natural gas for vehicle refuelling. The AGA and the BWR equations of state relating gas properties have been used to determine the amount of natural gas by weight, gas volume or heat content in a CNG automotive fuel cylinder. Direct temperature measurements were made during a carefully monitored quick fill.

RESULTS TO DATE:
Measurements during filling showed that the temperature dropped below ambient then started to increase until the temperature was 10 degrees C to 20 degrees C above ambient corresponding to a theoretical thermodynamic study which also showed a drop then increase in temperature. To account for this temperature deviation, an appropriate correction factor, determined from the results of the experiment and study, was incorporated into the computer program. The modified program was used to accurately estimate gas quantity from the initial and final fill pressure, cylinder size, gas composition and ambient temperature. The quantity of gas estimated agreed well with that measured by a commercial mass flow meter.

REPORTS/PUBLICATIONS
"CNG Measurements using PU7 Relationships", Richard P. Wyman, CNG Fuel Systems Ltd.

ORGANIZATION: CONCORDIA UNIVERSITY (1)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): PROF. T. KREPEC

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PROJECT TITLE: INJECTION & IGNITION OF HYDROGEN IN COMPRESS. IGNITION ENGINES WITH ELECTRONIC CONTROL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	HYDROGEN NATURAL GAS	IGN-QUALITY SPRAYS	FUEL-CONSUMPTION IGNITION EMISSIONS A/F RATIO MEP	

OBJECTIVES:
To develop an electronic fuel control system for direct injection of gaseous fuels into diesel engines.

METHOD:
A new gas injection system was developed using a microprocessor, linear digital actuators, and solenoid operated injectors.

RESULTS TO DATE:
The system has been developed. It operates on a 12V battery without amplification and with conventional solenoids. It operates with a frequency corresponding to 2000 RPM of a four-stroke diesel engine and at gas supply pressure of 200 bars. The system is optimized with the use of a mathematical model. A second, improved system is presently under development.

REPORTS/PUBLICATIONS:
T. Krepec, T. Tebelis, C.K. Kwok, "Fuel Control Systems for Hydrogen Fueled Automotive Combustion Engines. A Prognosis", International Journal of Hydrogen Energy, Vol.9, No.1/2, 1984, pp.109-114.
T. Krepec, T. Giannacopoulos, D. Miele, "New Electronically Controlled Hydrogen Gas Injector. Development and Testing", 6th World Hydrogen Energy Conference, Vienna, Austria, July 20-24, 1986.
T. Tebelis, T. Krepec, "A Concept of Electronically Controlled Hydrogen Gas Injector for High Speed Compression Ignition Engines", Proceedings of Second International Symposium on Hydrogen Produced from Renewable Energy, University of Miami, Cape Canaveral, Florida, U.S.A., Oct.22-24, 1985, pp.397-407.

ORGANIZATION: CONCORDIA UNIVERSITY (2)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): T. KREPEC (ROOM B-305)

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PROJECT TITLE: INJECTION & IGNITION OF NATURAL GAS IN DIESEL ENGINES WITH ELECTRONIC CONTROL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS HYDROGEN	IGN-QUALITY SPRAYS	EMISSIONS FUEL-CONSUMPTION OPERABILITY	TANKS-ON-BOARD

OBJECTIVES:
This research project is aimed at the development and optimization of an electronic injection system of gaseous fuels for diesel engines. It is based on solenoid operated injectors combined with a fuel metering valve actuated by a stepper motor. Both actuators remain under the control of a microprocessor which is synchronizing their action with the engine operation. This system is designed primarily to deal with natural gas and hydrogen. To reduce the ignition delay of these hard to ignite fuels, the research project includes also the development of an effective ignition support for these fuels after being injected into the combustion chamber of a diesel engine.

ORGANIZATION: DSMA-ATCON LTD.

ADDRESS:
:
TELEPHONE:

CONTACT PERSON(S):

PROJECT TITLE: DUAL FUELLING OF A TWO-STROKE C.I. ENGINE WITH NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY	

OBJECTIVES:
One object of this study was to investigate the technical feasibility of developing a dual fuel gas/diesel conversion system for two-stroke diesel engines.

METHOD:
The DDA 6V 71-N engine used in 10,000 Canadian buses was the subject of a design study of a "timed injection" system where natural gas is mixed with the inlet air as it enters the cylinder through the inlet ports. Control of the system is throug the normal governor mechanism.

RESULTS TO DATE:
The design study indicates that it is technically feasible to convert two-stroke diesel engines to natural gas with pilot injection.

REPORTS/PUBLICATIONS:
Report to Energy, Mines and Resources Canada.

ORGANIZATION: ECOLE POLYTECHNIQUE
DEPT: GENIE MECANIQUE
CONTACT PERSON(S): G. GOU

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PROJECT TITLE: EFFECT OF NATURAL GAS ON S.I. ENGINE PERFORMANCE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		FUEL-CONSUMPTION	

OBJECTIVES:
To compare the effects of gasoline and natural gas fuelling of a spark-ignition engine.

METHOD:
Two different series of tests have been conducted on a single cylinder Ricardo engine with variable compression ratios operating in the spark ignition mode: one series used natural gas (NG) as a fuel, the other one, gasoline.

The gasoline tests were run for maximum torque (i.e. optimum spark in advance and air/fuel ratio). With natural gas the same conditions were repeated but additional test runs were made keeping the mixture ratio as close as possible to stoichiometric.

RESULTS TO DATE:
The results obtained show that the volumetric efficiency was reduced by between 6 to 10% when the engine was using natur gas.

Typical values for the brake thermal efficiency were:
30% for NG operation (stoichiometric with 14:1 c.r.),
27% for NG with (variable air-fuel ratio and 14:1 c.r.), and
25% for gasoline with 8.6:1 c.r.

The thermal efficiency decreases with increasing RPM mainly because of the reduced volumetric efficiency and the additional friction.

REPORTS/PUBLICATIONS:

M. Gou, B. Detuncq and M. Perrault, "Comparison Between the Performances Obtained with Natural Gas and Gasoline on a Single Cylinder Spark Ignition Engine", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug.7-10, 1986.
M. Perrault, M. Gou et C. Guernier, "Simulation et analyse d'un systeme de carburation pneumatique pour vehicule au gaz naturel sour differentes conditions d'utilisation", 54e Congres ACFAS, Mai 1986, Montreal.
B. Detuncq, M. Perrault, M. Gou et C. Guernier, "Etude comparative des performances d'un moteur Ricardo fonctionnant a l'essence et au gaz naturel", 54e Congres ACFAS, Mai 1986, Montreal.
M. Gou, "L'utilisation du gaz naturel dans les transports", 15e Colloque Augustin Frigon, Decembre 1985, Montreal.
B. Detuncq, M. Gou, C. Guernier, M. Perrault, "Comparison Between the Performance Obtained with Natural Gas and Gasoline on a Single Cylinder Spark Ignition Engine", First International Power Conference and Exhibition, October 1986, Beijing.
M. Perrault, M. Gou, C. Guernier, "Simulation and Analysis of the Behaviour of a Pneumatic Carburation System for a Natural Gas Vehicle", Gaseous Fuels for Transportation International Conference, EXPO 86, August 1986, Vancouver.
Technical Reports:
M. Gou, M. Perrault, C. Guernier, "Simulation et analyse due comportement d'un systeme de carburation pneumatique pour vehicule au gaz naturel sous differentes conditions de temperature et de pression", rapport EPM/RT-86-2, Avril 1986, Ecole Polytechnique.
M. Gou, C. Guernier, B. Detuncq et M. Perrault, "Etude experimentale du comportement d'un moteur Ricardo fonctionnant au gaz naturel: premiere partie-essais gaz naturel", rapport EPM/RT-86-3, Fevrier 1986, Ecole Polytechnique.
M. Gou, C. Guernier, B. Detuncq, "Etude experimentale comparative du comportement d'un moteur Ricardo fonctionnant au gaz et a l'essence", rapport EPM/RT-86-4, Febrier 1986, Ecole Polytechnique.

Prospective Articles:
J. Baladi, F. Bozikovich, M. Gou, "Natural gas for Vehicles: a Canadian Perspective", Osaka Gas R & D, Osaka, June 1985.
F. Bozikovich, M. Gou, "Le gaz naturel carburant au Canada", GAZ D'Aujourd'hui, no.3, Mars 1986, Paris.

WE ALSO HAVE UNDERWAY:

1. Development of electronically controlled natural gas injection system;
2. Computer simulation of a pneumatic natural gas conversion system;
3. Effect of oxygen enrichment on the natural gas performance of a spark ignition engine;
4. Effect of small amounts of gasoline on the natural gas performance of a spark ignition engine.

ORGANIZATION: ENERGY MINES & RESOURCES (1)

ADDRESS:

CONTACT PERSON(S): MR. BERNIE JAMES

TELEPHONE:

PROJECT TITLE: EMISSIONS WITH NATURAL GAS FUELLING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		EMISS-EXHAUST	

OBJECTIVES:

1. To assess the characteristic exhaust emissions of natural gas fuelled vehicles in relation to emission standards.

METHOD:

Three vehicles were tested on natural gas and gasoline using EPA FTP and SOS test procedures.

RESULTS TO DATE:

Existing natural gas conversion systems appear to be capable of meeting the CO standards and HC standards if non-reactive hydrocarbons only are considered. The 1987 NOx emissions standards cannot be met by current conversion systems without the use of supplementary emissions control systems.

REPORTS/PUBLICATIONS
"Exhaust Emission Measurements of Natural Gas Fuelled Vehicles", Energy Mines and Resources Canada Report.
"Exhaust Emissions Measurements of Natural Gas Fuelled Vehicles Operating at Lean Air/Fuel Ratios", Energy Mines and Resources Canada Report.
"The Effect of New (1987) Regulations on the Emissions of NG Vehicles", Energy Mines and Resources Canada Report.

ORGANIZATION: ENERGY MINES & RESOURCES (2)

ADDRESS:
:

CONTACT PERSON(S): MR. BERNIE JAMES

TELEPHONE:

PROJECT TITLE: PROPANE AS AN AUTOMOTIVE FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	PROPANE/LPG		COLD START EMISS-EXHAUST FUEL-CONSUMPTION DURABILITY	

OBJECTIVES:
1. To provide technical information on the use of propane as an automotive fuel.

RESULTS TO DATE:
Includes compilation of information on engine durability, low temperature operation/starting, fuel consumption, emissions, research and development activity.

REPORTS/PUBLICATIONS:
"Propane, The Modern Automotive Fuel" 3rd, Edition, John S. Heenan, Energy Mines and Resources Report TE-84-12/E.

ORGANIZATION: ENERGY MINES & RESOURCES (3)

ADDRESS:
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CONTACT PERSON(S): MR. BERNIE JAMES

TELEPHONE:

PROJECT TITLE: NATURAL GAS AS AN AUTOMOTIVE FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	COMPOSITION	COLD START EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY	REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To provide technical information on the use of natural gas as an automotive fuel in Canada.

RESULTS TO DATE:
Includes compilation of information on fuel properties, safety, conversions, and research and development activity.

REPORTS/PUBLICATIONS
"Natural Gas, An Alternative Transportation Fuel". 2nd Edition, Energy Mines and Resources Canada Report TE-85-07, 1985.

ORGANIZATION: ESSO PETROLEUM CANADA (1)
DEPT: RESEARCH DIVISION
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PROJECT TITLE: EFFECT OF DIESEL FUEL COMPOSITION ON PERFORMANCE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV	IGN-QUALITY	COLD START	
	PROPANE/LPG	COMPOSITION	EMISS-EVAP	
			OPERABILITY	

OBJECTIVES:
To study the effects of diesel fuel properties upon ignition quality in anticipation of the expected decrease in fuel quality arising from the use of tar sands and cracked stocks.

METHODOLOGY:
The effects of fuel properties and engine operating conditions on ignition delay were studied in a single cylinder, direct injection 4-cycle engine (Petter engine). In conjunction with a Canadian General Standards Board (CGSB) Task Force a new relationship between measured cetane index (ASTMD613) and various fuel properties has been established.

SIGNIFICANCE:
Diesel fuel quality is expected to decrease with increased use of tar sands crude and the utilization of lower grade distillates previously used for heating oils. Information on the extent to which ignition quality can decrease without impairing engine performance is very useful for refiners.

STATUS:
Ongoing interest in diesel fuel quality

RESULTS:
- Ignition delay decreased non-linearly with increase in cetane number. Ignition delay also decreased, but linearly, with increase in the torque and the magnitude of the decrease is greater with lower cetane fuels.
- The ignition delay of fuel blends containing octylnitrate cetane improver are similar to natural diesel blends of the same cetane number.
- The CGSB Task Force developed cetane index is superior to other indices currently in use, particularly for lower cetane diesel fuels.

REFERENCES:
1. "Diesel Fuel Quality Trends in Canada" by D.E. Steere and T.J. Nunn, SAE Fuels & Lubricants Meeting, Houston, TX, SAE 790922, Oct.1979.
2. "Characteristics of Fuel Products from the Canadian Tar Sands" by D.E. Steere, W.A. MacDonald and J.H. Stone, American Petroleum Institute, May 1981, Preprint No. 14-81.
3. "The Effects of Diesel Fuel Properties and Engine Operating Conditions on Ignition Delay" by C.L. Wong and D.E. Steere. SAE Fuels & Lubricants Meeting, Toronto, Ontario, SAE 821231, October 1982.
4. "Development of the Canadian General Standards Board (CGSB) Cetane Index" by D.E. Steere, SAE Fuels & Lubricants Meeting, Baltimore, MD, SAE 841344, October 1984.

ORGANIZATION: ESSO PETROLEUM CANADA (2)
DEPT: RESEARCH DIVISION
CONTACT PERSON(S): J.B. GILBERT

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PROJECT TITLE: LIGHT HYDROCARBONS AS ALTERNATIVE TRANSPORTATION FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG		FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY DURABILITY	

OBJECTIVES:
1. To test the fuel economy, operability, and engine durability with dual fuelling of a diesel engine with propane and diesel fuel.

METHOD:
TNO conversion kits were installed on two trucks; LPG vapour introduced into the intake air manifold just before the turbocharger. The gas supply was controlled by the engine speed and load. One truck was adjusted for 40% by volume (vol) propane and the second truck was targetted for 20% vol propane. The two trucks were operated out of the Sarnia terminal from May, 1983 until April, 1985 in conjunction with a similar truck as a reference vehicle.

RESULTS TO DATE:
Fuel economy data accumulated over the test period showed essentially no difference between diesel fuel and dual-fuel operations on a total energy basis (1 litre of propane = 0.63 litre of diesel fuel).

Engine durability is reduced when LPG is used but, at about 20% vol LPG substitution, the effect is minimal. For higher levels of LPG substitution, improvements in valve and upper cylinder metallurgy may be necessary, as previously found in other LPG applications.

REPORTS/PUBLICATIONS
I.D. Campbell and J.B. Gilbert "Road Testing of 400 HP Turbocharged Diesel Engines Converted to Dual-Fuel Operation with Gaseous Fuels", Proc. Conf. in Gaseous Fuels for Transportation, Vancouver, B.C. Aug.7-10, 1986.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (1)
DEPT: INDUSTRIAL TECH. CENTRE
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PROJECT TITLE: REVIEW OF METHANOL FLEET TESTS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL		FUEL-CONSUMPTION OPERABILITY DURABILITY	

OBJECTIVES:
To review the results of 18 programs in 7 countries of fleet testing of the use of methanol and methanol-gasoline blends.

METHOD:
Each program was analyzed for the following: test design, number and type of vehicles, fuel formulation, vehicle performance, driving cycle, fuel consumption, problems or incidents.

RESULTS TO DATE:
Review has been completed.

REPORTS/PUBLICATIONS:
"Methanol Fleet Tests - A Review", prepared for Energy Mines and Resources Canada, Contract No. 0SQ84-00197.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (2)
DEPT: INDUSTRIAL TECH. CENTRE
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PROJECT TITLE: ENGINE WEAR AND MATERIAL COMPATIBILITY WITH METHANOL/FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL		DURABILITY	

OBJECTIVES:
To review recent literature on engine wear and material compatibility with methanol fuel.

METHOD:
A review has been made of laboratory immersion tests, and of engine wear studies. International fleet test results are summarized.

REPORTS/PUBLICATIONS:
C. Wm. Turner, "Engine Wear Rate and Compatibility with Methanol: Fuel Study, Energy Mines and Resources Canada Report TE-83-14, 1983.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (3)
DEPT: INDUSTRIAL TECH. CENTRE
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PROJECT TITLE: THE MANITOBA NEAT METHANOL FLEET TEST

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL OXY-WITH-GASOLINE	VOLATILITY COMPOSITION	COLD START FUEL-CONSUMPTION LUBRICANTS OPERABILITY DURABILITY	

OBJECTIVES:
The objective of this project was to test and demonstrate the use of neat methanol (90% methanol, 10% gasoline) as an automotive fuel by comparing the overall performance of a fleet operating on "M90" and one operating on gasoline.

RESULTS TO DATE:
The report was completed and submitted to Energy & Mines, Manitoba. Contact Al Jenkins, Manager, Energy & Mines, Manitoba, (204) 945-2791, for a copy of this report.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (4)
DEPT: INDUSTRIAL TECH. CENTRE
CONTACT PERSON(S): N. BERCUSON

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TELEPHONE: (204)945-6000

PROJECT TITLE: M85 METHANOL/GASOLINE BLEND VEHICLE FUEL DEMONSTRATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL	VOLATILITY	COLD START	
	OXY-WITH-GASOLINE	COMPOSITION	EMISSIONS	
			EMISS-EXHAUST	
			FUEL-CONSUMPTION	
			LUBRICANTS	
			OPERABILITY	

OBJECTIVES:
The objective of this project was to test and demonstrate the use of neat methanol (85% methanol, 15% gasoline) as an automotive fuel.

RESULTS TO DATE:
The final report is currently being prepared and will be submitted to Energy, Mines & Resources, Canada.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (5)
DEPT: INDUSTRIAL TECH. CENTRE
CONTACT PERSON(S): N. BERCUSON

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PROJECT TITLE: PROPANE FLEET TEST

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	PROPANE/LPG		FUEL-CONSUMPTION	
			OPERABILITY	

A copy of this report can be obtained from:
Al Jenkins
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Energy & Mines, Manitoba
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ORGANIZATION: MANITOBA RESEARCH COUNCIL (6)
DEPT: INDUSTRIAL TECH. CENTRE
CONTACT PERSON(S): N. BERCUSON

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: WINNIPEG, MAN. R2J 3T4
TELEPHONE: (204)945-6000

PROJECT TITLE: GASOHOL FLEET TEST

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	ETHANOL	VOLATILITY	FUEL-CONSUMPTION	
	OXY-WITH-GASOLINE	COMPOSITION	OPERABILITY	
			DURABILITY	

A copy of this report can be obtained from:
Al Jenkins
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ORGANIZATION: MANITOBA RESEARCH COUNCIL (7)
DEPT: INDUSTRIAL TECH. CENTRE
CONTACT PERSON(S): N. BERCUSON

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TELEPHONE: (204)945-6000

PROJECT TITLE: THE MANITOBA METHANOL FLEET TEST

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL	VOLATILITY	FUEL-CONSUMPTION	
	OXY-WITH-GASOLINE	COMPOSITION	OPERABILITY	

OBJECTIVE:
The objective of this project was to test and demonstrate the use of a low methanol/gasoline blend consisting of 5% methanol, 2% isobutane, 93% gasoline.

RESULTS TO DATE:
A report was given at the Proceedings of the 22nd ATM-CCM.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (8)
DEPT: INDUSTRIAL TECH. CENTRE
CONTACT PERSON(S): N BERCUSON

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PROJECT TITLE: MANITOBA METHANOL FLEET TEST

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL	VOLATILITY	COLD START	
	OXY-WITH-GASOLINE	COMPOSITION	EMISSIONS	
			EMISS-EXHAUST	
			FUEL-CONSUMPTION	
			LUBRICANTS	
			OPERABILITY	
			DURABILITY	

OBJECTIVE:
The objective of this project was to test and demonstrate the use of a low methanol gasoline blend consisting of 4.75% methanol, 4.75% isobutanol, 90.5% regular unleaded gasoline.

RESULTS TO DATE:
The final report has been submitted to Energy, Mines and Resources, Canada.

ORGANIZATION: MANITOBA RESEARCH COUNCIL (9)
DEPT: INDUSTRIAL TECH. CENTRE
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PROJECT TITLE: AMMONIA FUELLED ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	AMMONIA		EMISS-EXHAUST	
			HEAT TRANSFER	
			POWER OUTPUT	

OBJECTIVE:
Develop a prototype ammonia fueled engine capable of powering a 100 kQ electric generator for use in a remote location.

METHODOLOGY:
An 8.2L Detroit Diesel engine was modified for single cylinder Otto cycle operation and tested with ammonia at various compression ratios. Tests were also conducted using hydrogen addition to the ammonia. Ammonia is a source of hydrogen and its use avoids the cost and hazards of liquid hydrogen storage and the cost and weight penalty of metallic hydride storage.

SIGNIFICANCE:
The particular use covered by this research project was as a supplementary fuel for a windmill that generated electric power, part of which was used for ammonia production. The need to transport fuel to a remote location was thus avoided.

STATUS:
Project completed up to end of Phase II, Phase III not conducted because of termination of funds.

RESULTS:
No secondary fuel addition or combustion enhancers were required over the tested range of 1000 to 3000 rpm for smooth and efficient engine operation. The naturally aspirated engine achieved with ammonia a power output equal to that with a turbocharged engine using diesel fuel. Hydrogen addition did not provide increased power output however slightly higher thermal efficiency was obtained. Catalytic treatment of the exhaust gases reduced the unburned ammonia emissions to less than 50 ppm but under certain conditions increased the nitric oxide emissions.

REFERENCES:
"Experimental Development of an Ammonia Fueled Engine" by P. Shand, W. Thomas, G. Reese and C. Kristianson. Industrial Technology Centre/Manitoba Research Council, Winnipeg, Manitoba. May 10, 1985, DSS Contract Serial OSX83-00128.

ORGANIZATION: NATIONAL RESEARCH COUNCIL (1)
DEPT: GAS DYNAMICS LABORATORY
CONTACT PERSON(S): DR. R.G. WILLIAMSON

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PROJECT TITLE: COMBUSTION MODELLING IN A THROUGH FLOW COMBUSTOR

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	OTHER	FLAME-PROP	EMISSIONS	
GAS-TURB(MARINE)		OTHER		
GAS-TURB(INDUST)				

OBJECTIVE:
To develop a numerical model of spray combustion to investigate droplet burning in a pressurized steady flow combustion chamber.

METHOD:
The computer code will predict flow parameters, droplet distribution and chemical constituents in the combustion chamber given a set of starting conditions. A time-marching finite difference approach is used.

The computer code is an adaptation of a Los Alamos program called "Conchas Spray", which was developed to investigate the combustion in an internal combustion engine. The work on the NRC code has concentrated on changing the original combustion vessel from that of an IC engine to a through flow combustor.

EXPECTED RESULTS:
The computer code will predict flow parameters (velocity, temperature, pressures, etc.) "pseudo" fuel droplet distribution and chemical constituents. Since the program time marches through to a final steady state condition, the above calculated parameters will be determined from initial fuel injection to steady combustion.

ORGANIZATION: NATIONAL RESEARCH COUNCIL (2)
DEPT: GAS DYNAMICS LABORATORY
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PROJECT TITLE: DEVELOPMENT OF LASER DIAGNOSTIC TECHNIQUES FOR COMBUSTION SYSTEMS (IN GAS TURBINES)

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	TAR SANDS DERIV	LUMINOSITY		
GAS-TURB(MARINE)	OTHER	OTHER		
GAS-TURB(INDUST)				

OBJECTIVES:
To develop an apparatus for measuring soot particle sizes and number densities in flames.

METHOD:
Since soot formation is strongly dependent on local flow conditions, an in-situ, non-intrusive method of soot concentration and size measurement is essential for studies of its formation and control. The two main wavelengths from an argon-ion laser will be used for measurements of extinction and light scattering by particles to obtain information on soot produced in flames.

A subject of considerable interest is the use of lower grade liquid fuels in current combustion systems. Since these fuels are more prone to soot formation than conventional fuels, a means of measuring particle sizes and number densities in flames within these combustors is required in order to assess the impact of these low grade fuels. Measurement techniques developed on laboratory sized flames will be adapted for this purpose.

EXPECTED RESULTS:
The development of an apparatus for rapid in-situ measurements of soot size and concentration in steady-flow flames is the principal objective of this project. The apparatus will be based on established techniques and will be used to study soot formation in flames from low grade fuels.

ORGANIZATION: NATIONAL RESEARCH COUNCIL (3)
DEPT: GAS DYNAMICS LABORATORY
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PROJECT TITLE: MEAN DROPLET SIZE DISTRIBUTION MEASUREMENT

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	OTHER	OTHER		
GAS-TURB(MARINE)				
GAS-TURB(INDUST)				

OBJECTIVES:
To develop an apparatus for determining the mean drop size and size distribution of a cloud of droplets from measurements of light scattered by the liquid spray.

METHOD
When a uniform laser beam intercepts a cloud of droplets, its light is absorbed and scattered in several directions. In the present apparatus, the intensity distribution of light diffractively scattered in the far field is measured as a function of scatter angle. The characteristics of the spray, along the laser beam path, are derived from this distribution. The apparatus is suited to steady sprays only, since a finite time is needed for the intensity measurements.

Measurements of scattered light have been used extensively for characterising nozzle sprays in terms of mean droplet size. In the present case, this method is being extended to include predictions of mean size distribution.

EXPECTED RESULTS
The apparatus is expected to yield a mean drop size and a drop size distribution for a cloud of droplets. The method adopted makes no presuppositions of the form of the distribution. Since the intensity of scattered light is measured presently by a travelling detector the instrument is suitable for steady sprays only.

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PROJECT TITLE: DROPLET SIZE AND VELOCITY MEASUREMENTS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	OTHER	OTHER		
GAS-TURB(MARINE)				
GAS-TURB(INDUST)				

OBJECTIVES:
To measure the size, number densities and velocities of droplets at a point in a spray with a laser-doppler interferometer using the visibility-intensity technique.

METHOD:
Light scattered by a single droplet as it passes through interference fringes created by the crossing of two laser beams is used to determine the size and velocity of the droplet. Since the probe volume defined by the intersection point of the 2 beams can be made small, excellent resolution is obtainable so that detailed mapping of a spray is made possible.

The use of laser doppler interferometry for velocity measurement is well established. However, the extension of the method of spray droplet size measurement is not simple. Although visibility measurements are simple to make, the technique requires perfect fringe contrast and very careful alignment of optical components, making the apparatus impractical for widespread use. In the present case, absolute intensity measurements are included to support or reject the visibility-based size predictions.

EXPECTED RESULTS
It is well known that the Sauter Mean Diameter of the spray, which is a widely accepted measure of spray quality, depends on fuel properties such as viscosity, surface tension and liquid density. The exact correlations are, however, not always well established and depend furthermore on the method of spray formation. It is expected that better correlations will be derived. Additionally, the size distribution is important in various aspects of the combustion process. The effect of fuel properties on distribution is even less correlated than on the SMD. Important correlations are expected to be derive in the present program.

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PROJECT TITLE: DEVELOPMENT & APPLICATION OF OPTICAL DIAGNOSTIC TECHNIQUES TO GAS TURB. & DIESEL COMBUSTION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	OTHER	FLAME-PROP		
GAS-TURB(MARINE)		COMPOSITION		
		OTHER		

OBJECTIVES:
To develop and apply spectroscopic techniques and other optical techniques (shadowgraphy and direct visualization) to investigate continuous combustion problems relevant to gas turbines (and later to Diesel engines).

METHOD:
A broadband Coherent Anti-stokes Raman spectroscopy (CARS) system will be developed and used to perform temperature measurements. A laser-based shadowgraph/direct photography system will be designed for flow and spray visualisation measurements. Initially these techniques will be applied to flames and simple laboratory devices, but will later be extended to the study of practical devices.

Raman Spectroscopy has been used to determine spatially and temporally resolved measurements and composition in combustion gases. Since the spontaneous Raman signals are weak it is necessary to use non-linear techniques such as CARS to obtain data in radiant flames.

RESULTS TO DATE:
The techniques will be used to investigate the effect of fuel properties on the atomizing, mixing and ignition of droplet sprays. Droplet formation and droplet velocities will be investigated. Spontaneous Raman and CARS spectroscopy will be used to measure combustion temperatures and fuel/air mixing. The results will be used as inputs to combustion models being developed to describe combustion phenomena.

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PROJECT TITLE: FUEL ANALYSIS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV	COMPOSITION		
GAS-TURB(AIRCRAFT)	OXY-WITH-GASOLINE			
GAS-TURB(INDUST)				

OBJECTIVES:
- To develop analytical procedures that will provide structural and compositional information on hydrocarbon types in diesel and gas turbine fuels derived from tar sands crude.
- Correlate hydrocarbon structural and compositional data with combustion performance.
- To develop analytical techniques for analysis of oxygenated fuels.

METHODOLOGY:
Analytical techniques utilized include gas chromatography, liquid chromatography, gas chromatography/mass spectrometry and nuclear magnetic resonance and infrared spectroscopy.

SIGNIFICANCE:
Correlation of fuel hydrocarbon compostion/structure with combustion performance can provide a means of predicting fuel effects on engine operation. This type of correlation will be of benefit to both fuel producers and engine designers. Since alternative fuels derived from tar sands and lower quality petroleum fractions can be hydrogen deficient and contain higher molecular weight species compositional analysis is of particular importance for such fuels.

STATUS:
The limitations of the various analytical techniques noted under Methodology have been defined and the ability of both 1H and 13C nuclear magnetic resonance spectroscopy and gas chromatography/mass spectrometry to provide useful information on the composition of diesel and gas turbine fuels has been demonstrated. A large number of fuel samples have been analyzed by these techniques. The usefulness of gas chromatography for the analysis of more volatile fuels, e.g. methanol based fuels, has also been shown. Further work to expand the use of liquid chromatography and the continued utilization of NMR and GC/MS is anticipated.

RESULTS:
The ability to correlate certain combustion parameters with hydrocarbon structural information has been confirmed by the development of relationships for the prediction of cetane number.

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PROJECT TITLE: FUTURE DIESEL FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV	IGN-QUALITY	COLD START EMISS-EXHAUST OPERABILITY DURABILITY PARTICULATES	

OBJECTIVES:
To assess the combustion performance of future diesel fuels, such as those containing tar sands derived components, cracked stocks and residual products, in various types of diesel engines.

METHODOLOGY:
Working in conjunction with the Canadian General Standards Board (CGSB) a specification covering the projected requirements for a future diesel fuel has been drafted. A batch of fuel with a cetane number of 35 and higher than normal endpoint was produced in sufficient quantity to conduct engine tests in Canada, US, UK, FRG, and Japan. Smaller batches of other experimental fuels have also been prepared including one with an intermediate cetane number of 37. Engine tests have been conducted on a Detroit Diesel Allison (DDA) 3-71 and a DDA6V-92T. Other engines involved in the total program include the Cummins NTC400, Bombardier 251, and the Bombardier B2400 and Ricardo Hydra single cylinder research engines. Engines are instrumented to record various characteristics including intake air, fuel, engine oil, engine coolant and exhaust temperatures, cylinder pressure, injection timing and crankshaft position. Maximum cylinder pressure, rate of pressure increase and ignition delay are used to assess combustion performance. Exhaust gas analysis is also recorded and future requirements will include particulate level measurement.

SIGNIFICANCE:
The results obtained will help determine the limiting condition for ignition quality for the various types of high speed diesel engine and information on medium speed diesel combustion will be derived from the Bombardier B2400. Endurance tests will determine the longer term effect of high cylinder pressure and rapid pressure increase on the durability of engine components, engine deposits, etc. This information will enable producers to forecast the type and extent of processing required to satisfy the diesel market into the next century.

STATUS:
20 hr. tests have been completed on the DDA engines and a 500 hr. test has been completed on the DDA6V-91 and Bombardier 251 engines. Break-in runs have been completed on the Cummins NTC 400 engine and the Bombardier B2400 and its supporting systems are in the final stages of installation. The operation of the 1.5L VW Rabbit and 5.7L GM passenger car diesel engines on broad cut fuels has been completed. The work is ongoing.

RESULTS:

- With some restrictions on volatility for high temperature operation and in cetane number for low-temperature drivability and prevention of white smoke the broad-cut fuel approach appears feasible for the two passenger diesel engines tested.
- Although increased ignition delay periods, higher peak cylinder pressure and maximum rates of pressure increase were observed with short runs on the two DDA and Bombardier 251 engines no operating problems were encountered using low cetane fuel.
- Evidence of engine damage with the endurance (500 hour) runs of the DDA 6V-92 was observed but these may not be fuel related.

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PROJECT TITLE: HYDROGEN AS A DIESEL FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	HYDROGEN		OPERABILITY HEAT TRANSFER	

OBJECTIVES:

To design, develop and test optimized methods of injection of hydrogen at the highest achievable density to obtain maximum penetration and dispersion and thereby aid controlled homogeneous combustion.

METHODOLOGY:

Combustion and auto-ignition will be evaluated with air and noble gas mixture using a single cylinder research engine (Lister). A noble gas working fluid (compared to air) produces a higher pressure increase for the same compression ratio. Such an engine operates on a closed cycle.

Conversion of the Lister engine to a low heat rejection engine (LHRE) by installing ceramic piston and cylinder liners will also be investigated.

SIGNIFICANCE:

- Operation of diesel engines on a renewable fuel.
- Applications of closed cycle engines such as for submarine operation.
- Preliminary investigation of a LHRE.

STATUS:
The injector has been designed and a prototype manufactured, problems with this injector are being corrected by minor design changes. Compression measurements have been made on the un-modified engine with various mixtures of oxygen/helium. The ceramic components for conversion to LHRE have been obtained.

RESULTS:
Compression tests at 600 and 2,300 rpm show a temperature increase of 18% and 35% respectively compared with the naturally aspirated configuration.

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PROJECT TITLE: FUEL SPRAYS AND COMBUSTION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL GAS-TURB(AIRCRAFT)	TAR SANDS DERIV	IGN-QUALITY SPRAYS		

OBJECTIVES:
(1) To obtain a better understanding of the spray formation, pre-ignition and ignition under diesel engine conditions.
(2) Correlation of combustion related fuel properties.

METHOD:
(1) Combustion and spray characteristics are being investigated using a specially constructed combustion bomb and Laser diffraction light scattering techniques.
(2) Develop functional expressions for the prediction of thermochemical and combustion related characteristics from fuel structural composition and physical properties (see NRC "Fuel Analysis").

RESULTS:
(1) The experimental set-up for spray studies is in the early stages of use and initial data is being developed.
(2) Expressions have been developed for partial pressures of CO_2 and H_2O in combustion gases, cetane number and flame temperatures.

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PROJECT TITLE: MISSISSAUGA TRANSIT NATURAL GAS BUS DEMONSTRATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To demonstrate the practicality of operating transit buses on natural gas by using a North American engine. Obtain information on efficiency, reliability, economics and public acceptance.

This is a natural gas demonstration to be conducted by Mississauga Transit in cooperation with OBI, Consumers' Gas Fiba-Canning ORF, MTC and MENG. It will provide the first major experience with North American medium- to heavy-duty natural gas engines in buses.

METHOD:
- Obtain engine
- Engineer engine into an OBI bus
- Perform operational road testing/prove out (ORF)
- Operate the bus in the Mississauga Transit fleet
- Obtain operational data
- Produce report

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PROJECT TITLE: DEVELOPMENT AND TESTING OF LARGE METHANOL ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	METHANOL	IGN-QUALITY	COLD START EMISSIONS EMISS-EXHAUST	

OBJECTIVE:
To advance the medium- and heavy-duty methanol engine technology in cooperation with the Cummins Engine Co.

Methanol is one of the promising replacements for diesel fuel and helps reduce urban transit bus pollution (especially particulates).

With the involvement of Cummins Engine Co. a modified L10 diesel engine will be operated and tested using a cetane improved methanol fuel. Engine performance, fuel consumption, and emissions will be evaluated on the engine dynamometer.

METHOD:
- Obtain first generation methanol engine (requiring cetane improver)-HPRObtain fuel/cetane improver
- Install engine on dynamometer
- Evaluate performance, emissions, fuel consumption
- Carry out hardware and calibration mode functions
- Test second generation engine
- Perform single-cylinder research and produce second report

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PROJECT TITLE: DEVELOPMENT AND OPTIMIZATION OF DERECO PROPANE AND NATURAL GAS ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS PROPANE/LPG		FUEL-CONSUMPTION	

OBJECTIVES:
To determine the optimum operating mode for the DERECO propane and natural gas bus engines. This information will be used to ensure that the engines operating in the field are running at peak efficiency.

Because both of these engines are currently in service in provincial transit operations, and because some problems have been experienced with the engines while in service, it is desirable to verify that their existing operating parameters complement the environments in which they are operating. This program will provide this information, possibly yielding a more fuel efficient, longer lived ATF engine for the transit industry.

METHOD:
DERECO propane and natural gas engines will be optimized at ORF on a computer-controlled engine dynamometer. In addition to determining optimum mixture and spark advance schedules, a number of concerns which have arisen in the bus demonstration programs will be investigated (such as the need for a PCV system on the engine in its spark-ignited form).
1. one propane and one natural gas engine (both DERECO) will be installed on a computer-controlled engine dynamometer at ORF - one at a time.
2. Each engine will be optimized on its respective fuel under similar conditions to those experienced in the bus engine compartment.
3. Additional testing will also be performed on the engines based upon experience received in the ATF transit bus demonstrations which use the same engines.
4. The engines will be set up with the best possible set-ups (as determined in the above steps), and run on the dynamometer under simulated engine operating conditions (using the ADB cycle). This step will provide information on the relative engine operating efficiency (before and after figures will be available for comparison).

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PROJECT TITLE: NATURAL GAS TESTING AND CONVERSION OF AN 8.2 L DETROIT DIESEL ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS			

OBJECTIVE:
To develop a durable, compact domestic natural gas engine suitable for operation in either transit or medium duty truck applications.

METHOD:
An 8.2 Litre Detroit Diesel Allison (DDA) engine will be converted to natural gas and optimized on a computer-controlled dynamometer. The object of the exercise is to produce a durable natural gas engine, suitable for use in medium duty truck or transit bus applications. The 8.2 DDA engine is particularly suited to this application because it is a compact, low cost diesel which has been installed in a 40 ft. bus on a trial basis by GMC.
1. The 8.2 L engine will be converted to run on natural gas by reducing compression ratio, installing hardened valves and seats, and mounting natural gas fuel system and electronic ignition system.
2. The converted engine will be installed on a computer-controlled dynamometer at ORF for optimization of mixture and spark schedules on natural gas.
3. The optimized engine will be run on modified ADB cycles to estimate on-road fuel efficiency.

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PROJECT TITLE: CONVERSION OF MEDIUM-DUTY CUMMINS L10 DIESEL ENGINE TO NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS			

OBJECTIVE:
To develop a reliable medium-duty natural gas engine to displace some of the diesel fuel used by medium-duty trucks and buses.

To date, natural gas has not been able to penetrate the truck and bus sectors due to the absence of proven engine conversions which would perform well in these demanding applications. The Cummins Engine Co. has offered their cooperation in conversion of the L10 medium duty diesel engine to natural gas. This natural gas engine will be suitable for buses and trucks.

METHOD:
- Commission R&D organization to conduct project.
- Acquire a Cummins L10 engine and test it to establish baseline performance.
- Perform conversion to natural gas (cylinder head, pistons, ignition, etc.)
- Document conversion and test results.

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PROJECT TITLE: ICG PROPANE TRUCK DEMONSTRATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG		EMISSIONS FUEL-CONSUMPTION	

OBJECTIVE:
To demonstrate a domestic diesel engine, converted to run on propane, in a class 8 heavy-duty highway tractor. Two tractors will be converted; the first will enter revenue service in ICG's fleet. The second will be a show truck, to be entered in truck shows, conferences and seminars and will also be loaned out, for short periods of time, to prospective propane truck operators.

METHOD:
Two class 8 heavy-duty highway tractors will be converted to propane using converted Cummins 350 hp diesel engines. ORF will perform the engine conversions. Engines will be installed into new Western Star tractors at the factory in Kelowna, B.C. The tractors will be owned by ICG. One of them will be used for publicity while the second will transport bulk propane.

The procedure will be:
1. Convert the first tractor to propane using the engine developed as part of an earlier program.
2. Develop a second (new) engine at ORF and install it into the second tractor.
3. Rebuild a third engine at a heavy engine rebuild shop to propane specifications. This engine will be swapped with the original engine which was in the first tractor.
4. Both tractors will enter ICG fleet operation and publicity campaign upon completion.

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PROJECT TITLE: OC TRANSPO PROPANE BUS DEMONSTRATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG		FUEL-CONSUMPTION	

OBJECTIVE:
To demonstrate the practicality of operating a fleet of propane-powered transit buses. Obtain information on reliability, operating costs and public acceptance.

METHOD:
A total of 10 buses were converted to operate on propane fuel and entered into revenue service at OC Transpo. The engines were converted by DERECO and are fueled from an on-site bulk storage facility. Beginning this fiscal year revenue service will continue for a total of two years, during which time information concerning the economics and durability of the propane vehicles will be generated.

RESULTS TO DATE:
1. The ten buses were fitted with propane engines, fuel tanks and associated hardware.
2. An on-site propane storage and fueling facility was installed at OC Transpo.
3. An information gathering/processing system was designed and installed at OC Transpo to handle propane bus related information during operation.
4. One propane bus was tested for relative noise and vibration levels compared to the standard diesel-powered vehicles.
5. All buses were entered into revenue service, where they will be monitored until the end of the project.

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PROJECT TITLE: MODELLING OF METHANOL ENGINE COLD-STARTING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL OXY-WITH-GASOLINE		COLD START EMISSIONS FUEL-CONSUMPTION	

OBJECTIVE:
To evaluate the cold start performance of the Ford flexible fuelled engine under laboratory conditions and to develop a mathematical model of the process.

A Ford flexible fuelled engine will be installed in a temperature controlled cell. It will be started and run under load on a range of fuel mixtures between gasoline and M85 (85% Methanol). Measurements of fuel input conditions will be monitored and used to develop a computer model of the carburation process.

METHOD:
- Acquire FFV engine and mount with power absorption unit.
- Determine the lowest starting temperatures for a range of fuel mixtures between gasoline and M85.
- Warm up engine under load at few representative mixtures and temperatures, e.g. 0, -10, -15 degrees Centigrade and check for drivability faults.
- Model cold start function under port fuel injection conditions and identify factors important in promoting cold startability and warm up.

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PROJECT TITLE: DURABILITY EVALUATION OF METHANOL FUELED VEHICLES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL		DURABILITY	

OBJECTIVE:
To evaluate the engine durability of a fleet of methanol vehicles exposed to methanol over an extended time period and the efficacy of specially formulated oils in minimizing engine wear.

METHOD:
A group of vehicles which has already been exposed to straight methanol fuel for some time over previous projects, will complete their mileage accumulation beyond 100,000 km. Direct measurement of engine wear and analysis of oils will enable the long term durability of these engines to be assessed when operated with special oil formulations.

- Seven methanol Escorts and two gasoline Escorts will be run on a long distance mileage accumulation for 2 years using oil formulations developed in a prior project.
- Oil samples will be taken regularly and analysed for trace wear metals and bulk property changes.
- After a total distance accumulation exceeding 100,000 km at the end of a two year period, 4 vehicle engines will be stripped and measured for wear.

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PROJECT TITLE: IN USE EVALUATION OF CNG HOME COMPRESSOR

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS		OTHER	

OBJECTIVE:
To assess and demonstrate the technical and economic feasibility of CNG home refuelling with commercially available small compressor.

METHOD:
MTC has purchased a state of the art small compressor. The unit was installed at MTC Reservoir. It will be used to refuel MTC natural gas vehicles. During the process, the operating parameters, maintenance and safety records of this compressor will be evaluated.

The procedure will be:
- Operate and maintain compressor over a one year period keeping detailed records of operating parameters (e.g. hours of compressor operation, amount of fuel dispensed and electricity consumed, oil consumption, maintenance and repair procedures).
- Produce an economic analysis.
- Analyse data and prepare a project report.

ORGANIZATION: ONT. MIN. TRANSPORT & COMM(11)

ADDRESS: 1201 WILSON AVENUE
: TORONTO, ONT. M3M 1J8

CONTACT PERSON(S): DAVID ELLIOT

TELEPHONE: (416) 248-3771

PROJECT TITLE: DEVELOPMENT OF IMPROVED & COST EFFECTIVE CARBON ADSORBENTS FOR STORING CNG ON BOARD VEHICLES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS			

OBJECTIVE:
To generate and test new adsorbents capable of storing natural gas economically on board vehicles.

Polymers such as Saran will be incorporated with commercial carbons to generate new adsorbents. The aim will be to prepare materials which are better or cheaper than straight Saran carbon in storing compressed natural gas of commercial purity.

METHOD:
- Prepare composite adsorbents using Saran or other polymers incorporated with commercial carbon products.
- Investigate best packing modes including shaped blocks and pellets, e.g. tetrahedra.
- Investigate gas storage and delivery from selected materials when cycled repeatedly with commercial grade natural gas.

ORGANIZATION: ONT. MIN. TRANSPORT & COMM(12)

ADDRESS: 1201 WILSON AVENUE
: TORONTO, ONT. M3M 1J8

CONTACT PERSON(S): DAVID ELLIOT

TELEPHONE: (416) 248-3771

PROJECT TITLE: MTC/SUNCOR/AGC/MVMA METHANOL BLEND TEST PROJECT

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
	METHANOL ETHANOL OXY-WITH-GASOLINE			

OBJECTIVE:
To evaluate the acceptability of a methanol/ethanol/gasoline blend in the MTC fleet with respect to fuel consumption, emissions, reliability, durability and drivability. To examine the durability of component materials under fleet and laboratory conditions.

METHOD:
The use of ethanol as a cosolvent in methanol gasoline blends will be evaluated in new and used vehicles belonging to the MTC fleet. Fuel efficiency, performance and emissions will be measured by chassis dynamometer tests while drivability will be assessed in road tests. A separate lab-based project will look at the tolerance of fuel line related parts to the blend.

- New vehicles will be added to the existing MTC fleet.
- The fuel suppliers will supply a full engineered methanol blend containing ethanol as cosolvent to reduce risk of phase separating.
- This fuel will be evaluated in the MTC fleet for its effect on fuel consumption, emissions and drivability.
- An auxiliary project will examine component durability under laboratory conditions.

ORGANIZATION: ONT. MIN. TRANSPORT & COMM(13)

ADDRESS: 1201 WILSON AVENUE
: TORONTO, ONT. M3M 1J8

CONTACT PERSON(S): N. PERFECT

TELEPHONE: (416) 248-3771

PROJECT TITLE: ASSESSMENT OF COLD START PERFORMANCE OF CNG AND PROPANE VEHICLES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS PROPANE/LPG		COLD START	

OBJECTIVE:
To assist industry in identifying the causes of and solutions to widely reported vehicle startability problems with natural gas and propane vehicles.

Operators of CNG and propane vehicles experience problems starting engines under cold conditions. No successful, practical solutions exist at the moment, and wider acceptance of CNG and propane depends on eliminating these difficulties. The project will be aimed at finding solutions and implementing them.

METHOD:
1. Perform cold start tests on problem vehicles using refrigerated trailer at MTC.
2. Test to identify causes of problems such as conversion equipment, fuel composition, vehicle components, calibration.
3. Produce viable solutions to CNG and propane vehicle cold starting difficulties.

ORGANIZATION: ONT. MIN. TRANSPORT & COMM(14)

ADDRESS: 1201 WILSON AVENUE
: DOWNSVIEW, ONT. M3M 1J8

CONTACT PERSON(S): MR. T. TOPALOGLU

TELEPHONE: (416) 148-3771

PROJECT TITLE: NATURAL GAS VEHICLE CONVERSION KITS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY	

OBJECTIVES:
To evaluate the performance of commercial automotive compressed natural gas conversion equipment.

METHOD:
In the engine dynamometer tests, four typical conversion systems were assessed on 4.9 litre L6 and 6.1 litre V8 spark-ignition engines. Fuel consumption, power output, exhaust gas composition and temperature were measured under steady-state conditions over the load and speed ranges of the engine: both on gasoline (baseline tests) and on natural gas. For one of the conversion systems, the following parameters were measured and optimized: the dependence of peak power and part-load efficiency on carburation (air/fuel ratio), ignition (spark timing etc.), exhaust emissions control and engine .....

In the chassis dynamometer tests, two of the conversion systems were assessed on a pick-up truck equipped with the 4.9 litre engine. Fuel consumption and exhaust emissions were measured over the urban and highway driving cycles according to the Transport Canada guidelines (and USA/EPA regulations) on gasoline before and after conversion and while using natural gas.

RESULTS TO DATE:
The engine dynamometer tests indicated that, as a result of conversion to natural gas, maximum power and specific energy consumption deteriorate significantly, and optimization of spark timing and air/fuel ratio presents only a marginal potential in improvement.

The chassis dynamometer test results indicated that the conversion caused: only a modest increase in average energy consumption, both in the gasoline and natural gas modes; a significant deterioration in acceleration performance; an improvement in exhaust emission levels.

REPORTS/PUBLICATIONS:
T. Topaloglu, "Performance of First Generation NGV Kits: Engine and Chassis Dynamometer Test Results", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug. 7-10, 1986.

ORGANIZATION: ONTARIO RES. FOUNDATION (1)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S): A. LAWSON

PROJECT TITLE: DURABILITY OF SPARK IGNITION ENGINE USING NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		DURABILITY	

OBJECTIVES:
To determine the durability of a spark ignition engine using natural gas.

METHOD:
Intake and exhaust valve recess was evaluated on a 5.7 litre V8 engine operated on natural gas on an engine dynamometer. The engine was equipped with a commercially available add-on NG fuel system, consisting of a venturi type mixer and pressure regulator. The spark timing was adjusted using a dual curve module; operation on gasoline was maintained.

The accelerated wear test cycle consisted of wide open throttle operation, with engine speed varying (1 minute from peak to 25656. One cylinder bank carried a standard gasoline head, while the head on the other bank was replaced with a head which was modified for gaseous fuels (e.g. exhaust valve inserts).

RESULTS TO DATE:
During the first test series, the engine operated on natural gas for 200 hours. Valve recess on standard exhausts was about 0.050" per 100 hours of engine operation, while all intake and modified exhaust valves wore at a rate of 0.010" per 100 hours of engine operation.

A second 200 hour test series was conducted with the engine operating under a fuel cycle consisting of 4.5 hours on NG and 0.5 hours on gasoline. No significant difference was found in valve wear when compared to the first test series. Details on potential wear mechanism will be presented.

REPORTS/PUBLICATIONS:
W.A. Goetz and L. Gettel, "Durability of Spark Ignition Engine using Natural Gas", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug. 7-10, 1986.

ORGANIZATION: ONTARIO RES. FOUNDATION (2)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S): W.F. GOETZ A. LAWSON

PROJECT TITLE: SPARK IGNITION PROPANE ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		FUEL-CONSUMPTION OPERABILITY DURABILITY	

OBJECTIVES:
To test the performance of a diesel engine modified for spark ignition with natural gas.

METHOD:
A 260 kW propane engine suitable for installation in a Class 8 highway tractor has been developed. The engine is based on a 14 litre Cummins "Big Cam" propane engine used for stationary applications. Modifications to the ignition, fuel and governor system were introduced allowing transient operation of this engine over its entire speed and load range.

The engine was installed in a Class 8 truck with a maximum GVW rating of 59,000 Kg. During 1985 and 1986, a consumption and maintenance activity were recorded and compared to a similar diesel powered truck.

RESULTS TO DATE:
Combustion chamber pressures are significantly lower on propane compared to diesel, as identified in rate of pressure rise (P), and peak pressure (P max).

Fuel consumption data were collected with a diesel and propane engine, on a computer controlled dynamometer over a defined duty cycle. The increased volumetric fuel requirement on propane is due to (a) lower heating value of propane on a volume basis, and (b) lower thermodynamic efficiency caused by throttling and a reduced compression ratio.

REPORTS/PUBLICATIONS:
W.A. Goetz and W.M. Jones "Spark Ignition Propane Engine For Class 8 Trucks", Prof. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C., Aug.7-10, 1986.

ORGANIZATION: ONTARIO RES. FOUNDATION (3)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S): A. LAWSON

PROJECT TITLE: PROPANE FUELLED SPARK-IGNITION ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	PROPANE/LPG		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To develop a Cummins 350 HP propane engine for truck applications.

METHOD:
The engine was a diesel with modified cylinder heads, the CR was 8,5 and there was an air-to-air aftercooler plus a small turbo-charger (diesel 12-20 psi; LPG 7-9 psi) and a Delco HEI distributor.

RESULTS TO DATE:
The peak efficiency was given at about 1400 rpm at full load and when using propane gas the torque rise was 70% steeper than that given by the diesel fuel. There appeared to be no loss of vehicle efficiency and the next phase is to institute cold tests.

ORGANIZATION: ONTARIO RES. FOUNDATION (4)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S):

PROJECT TITLE: PERFORMANCE OF METHANOL BLENDS IN SPARK IGNITION ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL			

OBJECTIVE:
To determine the performance of engines with methanol blends in spark ignition engines.

ORGANIZATION: ONTARIO RES. FOUNDATION (5)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S):

PROJECT TITLE: SAFETY OF METHANOL USE IN TRANSPORTATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	METHANOL			REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To determine the safety of methanol use in transportation.

ORGANIZATION: ONTARIO RES. FOUNDATION (6)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S):

PROJECT TITLE: PERFORMANCE OF A FARM TRACTOR FUELLED WITH ETHANOL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	ETHANOL		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance of a farm tractor diesel engine fuelled with ethanol.

ORGANIZATION: ONTARIO RES. FOUNDATION (7)

ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
TELEPHONE: (416)822-4111

CONTACT PERSON(S):

PROJECT TITLE: PERFORMANCE OF A FARM TRACTOR FUELLED WITH CANOLA ETHYL MONOESTER BLENDS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	OTHER		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance of a farm tractor diesel engine fuelled with Canola ethyl monoester blends.

ORGANIZATION: ONTARIO RES. FOUNDATION (8)
ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
CONTACT PERSON(S):
TELEPHONE:

PROJECT TITLE: PERFORMANCE AND EMISSIONS OF A METHANOL FUELLED COMPRESSION IGNITION ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	METHANOL		EMISS-EXHAUST FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance and emissions of a methanol-fuelled compression ignition engine.

ORGANIZATION: ONTARIO RES. FOUNDATION (9)
ADDRESS: SHERIDAN PARK
: MISSISSAUGA, ONT. L5K 1B3
CONTACT PERSON(S): DR. A. LAWSON
TELEPHONE: (416) 822-4111

PROJECT TITLE: PERFORMANCE OF S.I. ENGINE VEHICLE WITH METHANOL/GASOLINE BLENDS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	OXY-WITH-GASOLINE		EMISSIONS FUEL-CONSUMPTION OPERABILITY DURABILITY	

OBJECTIVE:
To test the performance of spark ignition engines fuelled with methanol/gasoline blends.

METHOD:
Ontario Research Foundation, under contract to Celanese Canada Inc., recently completed its part in a two-year evaluation of a methanol/gasoline fuel blend for un-modified automotive engines.

RESULTS
Road tests showed that a methanol/gasoline blend (4.75% methanol, 4.75% cosolvent, 90.5% gasoline) performed just as well as unleaded gasoline in all respects. After one million kilometres under all driving conditions -- including temperatures as low as -36 degrees Celsius -- there was no difference in fuel consumption or in drivability between the test blend and regular gasoline. In addition, the test blend was found to produce slightly less carbon monoxide and hydrocarbon emissions. Engines that were driven 100,000 km on the test blend were torn down and carefully inspected. No unusual wear on these engines or their fuel systems could be detected and they were identical in every respect to control engines and components that had been operated on regular gasoline.

ORGANIZATION: PRATT & WHITNEY CANADA
DEPT: COMBUSTION LABORATORIES
CONTACT PERSON(S): DR. P. SAMPATH
ADDRESS: P.O. BOX 4080
: MISSISSAUGA, ONT. L5A 3Z4
TELEPHONE: (416)273-8410

PROJECT TITLE: ALTERNATIVE FUELS COMBUSTION RESEARCH

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	TAR SANDS DERIV OIL SHALE DERIV OTHER	FLAME-PROP FLAME-LIMITS VOLATILITY VISCOSITY COMPOSITION	COLD START EMISSIONS OTHER	

OBJECTIVE:
To test the effects of fuels derived from Oil shales, tar sands etc. upon the combustion characteristics within the P & W combustion systems - PT6A-65 and JT15D-5 and experimental can combustor.

METHOD:
Sixteen different fuels were tested within the above combustors so as to determine the effects of fuel properties upon stability, low temperature light-offs, gaseous emissions, smoke emissions, metal temperature and radiation heat loads.

RESULTS TO DATE:
Full details are given in Report No. AFWAL-TR-84-2042 (ESL-TR-84-29). Lean blow-out stability limits were influenced by fuel hydrogen content and spray quality, and to a lesser extent by fuel volatility. Cold start tests were related to fuel atomization. Steady state tests indicated that CO, HC and smoke were strongly influenced by fuel hydrogen content; fuel effects on take-off NOx emissions were small but were significant at idle due to changes in combustion efficiency. Radiation heat loads and liner temperatures were strongly influenced by hydrogen content and by properties affecting atomization characteristics. Smoke emissions were sensitive to fuel hydrogen content, aromatic content injector design and to the type of aromatics present within the fuel. Carbon check tests on the can combustor were inconclusive, possibly due to carbon shedding with several fuels. Combustor exit temperature distributions were found to be sensitive to changes in the composition as well as to the physical properties of the fuels.

ORGANIZATION: ROYAL MILITARY COLLEGE (1)
DEPT: CHEMISTRY AND CHEMICAL ENGG
CONTACT PERSON(S): DR. S.S. BARTON DR. J.R. DACEY DR. D.F. QUINN
ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7457 OR 7318

PROJECT TITLE: COMPOSITE CARBONS FOR METHANE ADSORPTION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS	OTHER		

OBJECTIVES:
To produce a composite material for adsorption of methane.

METHOD:
Tests were performed to examine combining the AMOCO superactivated carbon with a polymer derived carbon to possibly produce a material with the needed properties.

RESULTS TO DATE:
Tests indicate that composite carbons can be made with Amoco GX-32 and polyvinylidene chloride carbon or polyvinylidene fluoride carbon. Further improvements on storage densities for methane are thought likely and possibilities are available.

REPORTS/PUBLICATIONS:
Barton, S.S., Dacey, J.R., Evans, M.J.B., Holland, J.A., and Quinn, D.F., "The Production and Evaluation of Composite Carbons for the Adsorption of Methane", (Report #AF-84-04, Ontario Ministry of Communications) Royal Military College of Canada, Kingston, Ontario, 28 pp.

ORGANIZATION: ROYAL MILITARY COLLEGE (2)
DEPT: CHEMISTRY & CHEMICAL ENGG.
CONTACT PERSON(S): DR. S.S. BARTON DR. J.R. DACEY DR. D.F. QUINN
ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7457 OR 7318

PROJECT TITLE: ADSORPTION OF NATURAL GAS ON POROUS CARBONS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS	OTHER		

OBJECTIVES:
To increase the storage density of natural gas by high pressure adsorption on porous carbons.

METHOD:
Volumetric adsorption of methane by six microporous carbons was measured at -30, 0 and 25 C, and by two molecular sieves at 25C, at pressures up to 20 MPa.

RESULTS TO DATE:
The measurements indicate that the microporous carbons are efficient adsorbents for methane, all adsorbing more methane than the molecular sieves. Methane adsorption is enhanced at lower temperatures. Also, storage density increases at pressures below 80 atmospheres and decreases at pressures above 150 atmospheres.

REPORTS/PUBLICATIONS
Barton, S.S., Dacey, J.R., Quinn, D.F., "High Pressure Adsorption of Methane on Porous Carbons", Fundamentals of Adsorption, ed. A.L. Myers, Engineering Foundation Conferences (1983), p.65. Also Report #AF-84-01, Ministry of Transportation, Government of Ontario, Toronto, M3M 1J8.

ORGANIZATION: ROYAL MILITARY COLLEGE (3)
DEPT: CHEMISTRY & CHEMICAL ENGG.
CONTACT PERSON(S): DR. S.S. BARTON DR. J.R. DACEY DR. D.F. QUINN
ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7457 OR 7318

PROJECT TITLE: SOLID ADSORBENTS FOR NATURAL GAS FOR AUTOMOTIVE USE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS	OTHER		

OBJECTIVES:
To develop solid adsorbents for storage of compressed natural gas for automotive use.

METHOD:
Saran carbon was examined as an adsorbent for methane at pressures up to 10,3 MPa. The size of the micropores was shown to be very important in deciding the quantity of methane adsorbed. Steam activation and heat treatment activation were both assessed.

RESULTS TO DATE:
On a mass of adsorbent basis, adsorption of methane is increased considerably by the use of steam activation. A fill time of 15 minutes resulted in about 90% of equilibrium. Gas densities achieved so far at 3,44 MPa are 92 g/L, which is significantly greater than any other system currently reported.

REPORTS/PUBLICATIONS:
Report #AF-85-01, March 1985, Ontario Ministry of Transportation, Toronto, M3M 1J8. Also in Fundamentals of Adsorption II, ed. A. Liapis, Engineering Foundation Conference, May, 1986.

ORGANIZATION: ROYAL MILITARY COLLEGE (5)
DEPT: CHEMISTRY & CHEMICAL ENGG.
CONTACT PERSON(S): S.S. BARTON D.F. QUINN J.A. HOLLAND
ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7457 OR 7318

PROJECT TITLE: ADSORPTION OF METHANE BY COMPOSITE CARBONS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS	OTHER	OTHER	

OBJECTIVES:
Further development of adsorbents for compressed natural gas for automotive use.

METHOD:
Composite carbons made from Saran polymer were investigated for natural gas adsorption. This was related to the physical properties of the carbon. Fill-empty cyclic testing was carried out on some of these carbons.

RESULTS:
While Saran carbon was shown to adsorb a greater amount of methane per unit volume than any other carbon, a composite carbon delivered more methane, 105 volumes per volume of storage, from 500 psi.

Fill empty cyclic testing using natural gas showed an initial reduction in gas delivered of some ten percent but this did not decrease further, even after more than one hundred cycles.

REPORTS/PUBLICATIONS
Report to Ontario Ministry of Transportation and Communication, March 1986.

ORGANIZATION: ROYAL MILITARY COLLEGE (6)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): M.F. BARDON V.K. RAO
ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7376 OR 7369

PROJECT TITLE: COLD STARTING OF METHANOL FUEL BLENDS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL OXY-WITH-GASOLINE		COLD START MODELLING	

METHOD:
Tests on the cold starting performance of methanol fuel blends including primed and unprimed methanol/gasoline formulations.
Mathematical modelling of cold starting, including manifold film flows, droplet evaporation, heat transfer, ignition and flame propagation, blowby.

PUBLICATIONS:
M.F. Bardon, "Thermodynamic Calculations for Otto Cycle Engines Using Methanol as a Fuel", Alternative Energy Sources II, Vol.7, No.15, pp.
M.F. Bardon, 'Comparison of the Cold Temperature Performance of Gasoline and Alcohols in Spark Ignition Engines", ASME paper #80-PET-17, presented at the Energy Sources Technology Conference, New Orleans, Feb. 3-7, 1980.
D.P. Gardiner and M.F. Bardon "Cold Starting Tests on a Methanol Fuelled Spark Ignition Engine", Fuel Alternatives for Spark Ignition Engines, SP-548, Society of Automotive Engineers, Warrendale, PA, 1983.
M.F. Bardon, V.K. Rao and D.P. Gardiner, "An Experimental and Theoretical Comparison of Methanol and Gasoline Cold Starting Performance", Proc. VI Intl. Symp. on Alcohol Fuels Technology, Vol. 16-22, Ottawa, May 21-25, 1984.
M.F. Bardon, V.K. Rao and D.P. Gardiner, "The Effect of Droplet Vaporization Rate on the Cold Starting Characteristics of a Methanol Fuelled Engine", Combustion Institute, Canadian Section Spring Technical meeting, Fredericton, May 24-25, 1984.

M.F. Bardon, D.P. Gardiner and V.K. Rao, "Cold Starting Performance of Gasoline/Methanol M10 Blends in a Spark Ignition Engine", SAE Paper #850214 presented at the Society of Automotive Engineers' International Congress, Detroit, Feb.25-Mar.1, 1985.
D.P. Gardiner, M.F. Bardon, "Mixture Maldistribution due to Manifold Films in a Methanol Fuelled SI Engine", SAE Paper #860234, presented at the International Congress and Exhibition, Detroit, Feb.24-28, 1986.
D.P. Gardiner and M.F. Bardon, "The Effect of Cranking Speed on Cold Starting Performance with Methanol Fuels", presented at the VII Intl. Symp. on Alcohol Fuels, Paris, Oct.20-23, 1986.
D.P. Gardiner, S.G. Caird and M.F. Bardon, "Spark Ignition Engine Cold Starting with Methanol-based Fuel Blends", SAE paper accepted for presentation at the Intl. Congress & Exhibition, Detroit, Feb.23-27, 1987.

ORGANIZATION: ROYAL MILITARY COLLEGE (7)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): M.F. BARDON V.K. RAO

ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7376 OR 7369

PROJECT TITLE: VAPOUR PRESSURE OF GASOLINE AND METHANOL-GASOLINE BLENDS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
	METHANOL OXY-WITH-GASOLINE	VOLATILITY		

OBJECTIVE:
Modelling and experimental determination of vapour pressure and other volatility characteristics of conventional hydrocarbon fuels and methanol/hydrocarbon blends.

PUBLICATIONS:
M.F. Bardon and V.K. Rao "Calculation of Gasoline Volatility", J. Inst. Energy, Vol.57, pp.343-348, Sept. 1984.
V.K. Rao and M.F. Bardon, "Estimating the Molecular Weight of Petroleum Fractions", Ind. Eng. Chem, Process Des. Dev., Vol.27, No.2, April 1985.
"A Vapour Pressure Model for Methanol/Gasoline M85 Blends", SAE paper accepted for presentation at the International Congress and Exposition, Detroit, Feb.23-27, 1987.

ORGANIZATION: ROYAL MILITARY COLLEGE (8)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): M.F. BARDON V.K. RAO

ADDRESS: : KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7376 OR 7369

PROJECT TITLE: IGNITION DELAY

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV METHANOL OXY-WITH-DIESEL	IGN-QUALITY	COLD START	

OBJECTIVE:
Ignition delay tests in rapid compression machine and single cylinder research engine.

ORGANIZATION: ROYAL MILITARY COLLEGE (9)
DEPT: MECHANICAL ENGINEERING
CONTACT PERSON(S): M.F. BARDON V.K. RAO

ADDRESS:
: KINGSTON, ONT. K7K 5L0
TELEPHONE: (613)545-7376 OR 7369

PROJECT TITLE: BLUFF BODY FLAME STABILIZATION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	TAR SANDS DERIV	FLAME-LIMITS	MODELLING	

OBJECTIVE:
Bluff body flame stability of standard and degraded specification fuels.
Afterburner modelling.

PUBLICATIONS:
J.A. DeChamplain and M.F. Bardon "A Model for Bluff Body Flame Stabilization", ASME paper #86-GT-155 presented at the International Gas Turbine Conference and Exhibit, Dusseldorf, June 8-12, 1986.

ORGANIZATION: SPACE FUEL PRODUCTS LTD.

ADDRESS:
: CALGARY, ALTA

CONTACT PERSON(S):

TELEPHONE:

PROJECT TITLE: DUAL FUELLING OF A DIESEL ENGINE WITH PROPANE AND NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG		FUEL-CONSUMPTION OPERABILITY DURABILITY	

OBJECTIVES:
To determine the performance of a diesel engine with dual fuelling with propane and diesel.

METHOD:
The converted engine was an International Harvester model 573B (260 HP) with the propane inducted into the engine with the air flow. The horsepower of the engine was not altered. Tests were conducted on an engine dynamometer.

RESULTS TO DATE:
Partial substitution of diesel with propane resulted in lower air intake manifold and exhaust temperatures, and raised cylinder pressure (both peaks and the fluctuating component). It was concluded that a propane/diesel (weight basis) ratio of 0.25 would not adversely affect the life of the engine.

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PROJECT TITLE: SAFETY OF NATURAL GAS AS A GROUND TRANSPORTATION FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	NATURAL GAS			REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To compile information on the safety of natural gas as a ground transportation fuel.

METHOD:
A study has undertaken to gather, analyze, and disseminate technical information on the safety of natural gas as a ground transportation fuel. In addition, established procedures for fast-fill and slow-fill systems were examined, as were the newly developed absorption systems.

RESULTS TO DATE:
In general no insurmountable problems were found though considerable care must be exercised when designing and operating a CNG retail outlet.

REPORTS/PUBLICATIONS
Hallett, Patrick H., Heenan, J., "Safety of Natural Gas Retail Storage, Refueling and Use in Road Vehicles", 22nd Automotive Technology Development Contractors' Coordination Meeting, Oct.29-Nov.2, 1984, pp.81-88 (SAE P-155).

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PROJECT TITLE: SAFETY OF NATURAL GAS FUELLED VEHICLES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS			REFUELLING
SPARK IGNITION	PROPANE/LPG			TANKS-ON-BOARD
				COLLISION

OBJECTIVES:
To assess the available information on safety of natural gas fuelled vehicles and fuelling systems.

METHOD:
Literature review.

RESULTS:
A summary of the safety of propane and natural gas fuelled vehicles in Canada. Information is provided on vehicle tests conducted for regulatory and development purposes and also on tests conducted to determine the compliance of production vehicles with government safety standards. Data is provided on accidents involving the subject type of vehicles and comments are made on the integrity of compressed natural gas containers, as well as other relevant aspects of safety.

A general conclusion is that when properly handled, gaseous fuels are as safe as gasoline.

REPORTS/PUBLICATIONS:
R.V. Myers, "Safety of Gaseous Fuelled Vehicles in Canada", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug.7-10, 1986.

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PROJECT TITLE: COMBUSTION OF GASEOUS FUELS IN VARIOUS OXYGEN-INERT MIXTURES .. etc.

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(INDUST)	PROCESS GAS	FLAME-PROP		
	NATURAL GAS	FLAME-LIMITS		
	PROPANE/LPG			
	OTHER			

OBJECTIVE
To assess the influence of tube geometry, cross-sectional area and fuel/oxygen/inert composition upon the rate of flame travel and combustion limits; to assess the fundamental burning rate (Su).

METHOD:
Any or all of five different gases are mixed in known quantities and delivered to the combustion tube (L = 1,5m). By means of remote switching a pneumatic shutter opens the top of the tube to the atmosphere at the same time that spark ignition is applied. As the flame travels down the tube its rate of progress is measured by a series of thermocouples which signal their temperature responses to an event recorder. Knowing the distance between thermocouples enables the rate of flame travel to be measured. Tests are done over a full range of mixtures from weak to rich, and both flame extinction limits are also determined. It is possible to determine the fundamental flame speed by extrapolating (logarithmically) the measured rates of flame travel versus tube diameter to the quenching diameter. A wide variety of tube cross-sections of circular, semi-circular, square, rectangular, diamond, etc. have been tested.

The fuels used for the experiments are - H_2, CO, CH_4 and C_3H_8: O_2 is the sole oxidant; diluents used are N_2, CO_2, He and Ar. The fuels were tested singly, or in combinations of two components, over a range of equivalence ratio. Diluents were tested singly or in combination with air.

RESULTS TO DATE: The data will extend the knowledge of rates of flame travel, flame limits and fundamental flame speeds for a wide combination of mixtures. A new weak limit prediction technique has been developed which replaces the Le Chatelier technique and has much wider application. The technique has been shown to apply to industrial furnaces and gas turbines. It is hoped to develop a similar technique for rich extinctions and to predict flame travel for any mixture. The results also give indications as to the minimum size and geometry of combustor one may have without wall effects affecting the combustion process.

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PROJECT TITLE: BEHAVIOUR OF ALT. FUELS IN SMALL TRANSPARENT COMBUSTOR ... etc.

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)	TAR SANDS DERIV	FLAME-PROP	EMISSIONS	
GAS-TURB(MARINE)	OIL SHALE DERIV	FLAME-LIMITS	FUEL-CONS	
GAS-TURB(INDUST)	OTHER	LUMINOSITY	OTHER	
		IGN-QUALITY		
		VOLATILITY		
		VISCOSITY		
		COMPOSITION		

OBJECTIVE:
To relate combustion behaviour to fuel type and composition so as to predict the effects upon combustor life, exhaust characteristics, emissions.

METHOD:
The fuels are tested at a single operating condition (P3= 0,1 MPa, T3=350 K) over a range of air/fuel ratios. Measurements are made of CO_2, CO, HC, O_2 NO and NOx, exhaust temperature distribution and carbon content, flame radiation and weak extinction. A transparent steady-flow conductor has been used, with internal diameter of 46 mm.

Some 30 fuels have been selected, derived from 20 compounds (exceptions JP4, JP10 and RJ6). Their performance is compared with that of a base fuel (mixture of 5 paraffins). By adding compounds separately, or in combination with the base fuel, changes of behaviour are identified to a particular compound(s). In addition, the behaviours of single compounds are also investigated. Since the air-assist atomiser is very efficient the droplet sizes are very small (13 - 17 um) and the performance resembles that of a premixed system. Therefore, one would expect droplet effects to be very small and 'chemical' effects to predominate.

RESULTS TO DATE:
The data should (1) enable the effects of 'chemical' differences to be identified, (2) identify those combustion effects which can readily be measured at atmospheric pressure, (3) indicate possible scale effects upon combustion. The results are of interest to builders and operators of both aircraft and industrial gas turbines which have to operate on 'alternative' fuels.

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PROJECT TITLE: ALTERNATIVE FUELS FOR GASOLINE ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL	KNOCK-LIMITS	EMISSIONS	
	ETHANOL	VOLATILITY		
	OTHER	COMPOSITION		
		OTHER		

OBJECTIVES:
To determine the influence of fuel type upon the combustion behaviour within a single cylinder ASTM-CFR engine.

METHOD:
The engine is operated at a constant speed (900 RPM) with carefully controlled inlet air temperature and humidity, over a range of equivalence ratios and compression ratios. Measurements are made of the P-V diagram, torque, CO_2, CO, HC, O_2, NO and NOx, exhaust carbon and knock.

The 'standard' fuel is an unleaded gasoline and to this fuel amounts of methyl-, ethyl- and iso-propyl alcohol are added ranging from 0 to 50% alcohol. Knock rating measurements are also made. Additional studies are to be made to determine the effects of operating the engine on pure hydrocarbon compounds and their mixtures. Some 30 fuels will be tested but with a smaller range of operating conditions than with the alcohols. The objectives are to establish what effects the various compounds, separately or in combination, have upon the performance of the combustion within the engine from the viewpoint of power, stable combustion, knock and pollutants. In addition, since many of the 30 hydrocarbon fuels will be tested within a gas turbine combustor, it should be possible to draw comparisons of the behaviour of fuels under both steady-state and intermittent combustion.

RESULTS TO DATE:
The results should be of considerable interest to the users of both types of engines. With respect to the alcohols, results to date suggest that generally, other than knock, after suitable carburettor adjustment, the effects of fuels are small in comparison with the effects due to changes in equivalence ratio.

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PROJECT TITLE: BEHAVIOUR OF ALT. FUELS IN A SMALL CONVENTIONAL COMBUSTOR HAVING A SIMPLEX INJECTION SYSTEM ... ETC.

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(AIRCRAFT)		FLAME-PROP	EMISSIONS	
GAS-TURB(MARINE)		FLAME-LIMITS	EMISS-EXHAUST	
GAS-TURB(INDUST)		LUMINOSITY	FUEL-CONSUMPTION	
		IGN-QUALITY	OTHER	
		VOLATILITY		
		VISCOSITY		
		COMPOSITION		

OBJECTIVE:
To relate combustion behaviour to fuel type and composition so as to predict the effects upon combustor life, exhaust characteristics and emissions.

METHOD:
The fuels are tested at a single operating condition (P2=0, 1 MPa; T3=350 K) over a range of air/fuel ratios. Measurements are made of CO_2, CO, HC, O_2, NO and NOx, exhaust temperature distribution and carbon content, Red-Green Brightness temperatures of the flame, and weak extinction characteristics.

Some 30 fuels have been selected, derived from 20 compounds (exceptions JP4, JP10 and RJ6). Their performance is compared with that of a base fuel (mixture of 5 paraffins). By adding compounds separately, or in combination, to the base fuel, changes of behaviour are identified to a particular compound(s). In addition, the behaviour of single compounds are also investigated. Since the injector used is a simple pressure-jet atomiser, it is anticipated that the predominant effects will depend upon droplet size and that the resultant performance will be characterised by both droplet and 'chemical' effects, the former being thought to predominate.

RESULTS TO DATE:
In conjunction with the results from the transparent combustor reported above, this particular programme should enable to identify (1) the effects of droplets upon combustion performance, (1) those combustion effects which can be measured readily at atmospheric pressure, (3) indicate possible scale effects upon combustion. All the results are of interest to builders and operators of gas turbines which have to use alternative fuels.

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PROJECT TITLE: KNOCK DETECTION IN ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS PROPANE/LPG	FLAME-PROP KNOCK-LIMITS IGN-QUALITY		

OBJECTIVES:
To develop a new method of knock detection in engines.

METHOD:
An algorithm has been developed to characterize the severity of the bulk pressure change associated with knocking combustion. This algorithm depends on the third derivative of the pressure around the time of peak pressure. A large negative value of the third derivative indicates the abrupt pressure rise and sharp peak commonly associated with gas combustion.

RESULTS TO DATE:
This knock diagnostic works on a low frequency data acquisition rate (1 point/CAx or less) and produces consistent results in spite of high frequency raise on the pressure signal such as might be caused by resonance of a spark plug-mounted pressure transducer.

REPORTS/PUBLICATIONS:
M.D. Checkel and J.D. Dale, "Computerized Knock Detection from Engine Pressure Records", SAE Paper 860028.
M.D. Checkel and J.D. Dale, "Testing a Third Derivative Knock Indicator on a Production Engine", SAE Paper 861216.

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PROJECT TITLE: PLASMA IGNITION SYSTEMS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	PROPANE/LPG	IGN-QUALITY OTHER		

OBJECTIVES:
To develop a high energy (plasma jet) ignition system.

METHOD:
The performance of various plasma ignition systems has been studied in a CFR engine. This included a standard spark plug, an extended spark plug, a surface discharge plug, and two plasma jet igniters, one with open cavity and the other with a jet forming orifice. For all tests the engine was run with a compression ratio of 8:7, wide-open throttle and MBT timing.

RESULTS TO DATE:
Information was obtained on ignition delay, combustion deviation efficiency, emissions and knock limits.

REPORTS/PUBLICATIONS:
C.F. Edwards, A.K. Oppenheim and J.D. Dale, "A Comparative Study of Plasma Ignition Systems", SAE 830479.

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PROJECT TITLE: LOW TEMPERATURE STARTING OF DIESEL ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	DIESEL	IGN-QUALITY	COLD START	

OBJECTIVES:
To develop a timed high energy spark discharge system to aid in low temperature starting of diesel engines.

METHOD:
The tests were conducted by cold soaking the engines in a low temperature chamber in temperatures as low as -55xC. An Arctic (AA) Diesel fuel was used at these low temperatures while B(No.2) fuel was used at warmer temperatures.

RESULTS TO DATE:
The timed spark discharge system produced more rapid starts and faster warm-up at lower temperatures and consumed equal or less electrical energy when compared to factory fitted glow plugs.

REPORTS/PUBLICATIONS:
J.D. Dale, J.D. Wilson, J. Santiago, P. Smy and R. Clements, "Low Temperature Starting of Diesel Engines, Using Timed Spark Discharge", SAE 850049.

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PROJECT TITLE: PERFORMANCE OF A SINGLE CYLINDER ENGINE WITH NATURAL GAS FUELLING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	FLAME-PROP IGN-QUALITY	FUEL-CONSUMPTION MODELLING	

OBJECTIVES:
To determine the performance of a single cylinder research engine with natural gas fuelling and its predictability from a turbulent flame analysis.

METHOD:
Measurements over a range of mixture ratios and speeds were compared with an engine simulation model using estimate of turbulent combustion parameters obtained from knowledge of small scale turbulence.

RESULTS TO DATE:
The model successfully predicts the trends in combustion rate when the engine speed and mixture strength are varied.

J. Boisvert, "Turbulent Combustion of Gas-Air Mixtures in a Spark Ignition Engine", Alternate Fuels Laboratory, University of British Columbia Department of Mechanical Engineering, Engineering Report No.AFL-86-05, 1986.

ORGANIZATION: UNIVERSITY OF B.C. (2)
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PROJECT TITLE: LAMINAR FLAME VELOCITY OF METHANE IN AIR WITH ETHANE AND PROPANE ADDITIVES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	FLAME-PROP		

OBJECTIVES:
To determine the laminar burning velocity of methane with variable propane and ethane content.

METHOD:
Pressure rise measurements were made in a spherical chamber with central ignition and initial pressure on the range 1-8 atm. Two analytical methods were used to deduce burning velocity from pressure time derivatives.

RESULTS TO DATE:
Laminar burning velocities of stoichiometric mixtures of methane and air, propane and air, and ethane and air as well as of methane and propane or ethane mixtures (up to 20% volume percent additive). These additives release the burning velocity of methane-air by amounts depending on the concentration and initial pressure. Ethane appeared to be more effective than propane for the same volume per cent.

REPORTS/PUBLICATIONS:
J. Hung, "Effects of Propane on Ethane additives on Laminar Burning Velocity of Methane-Air Mixtures", Alternative Fuels Laboratory, Department of Mechanical Engineering, University of B.C., Report AFL-86-04, May 1986.

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PROJECT TITLE: PERFORMANCE OF A SINGLE CYLINDER RESEARCH ENGINE FUELLED WITH NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance of a spark-ignition engine fuelled with natural gas or gasoline.

METHOD:
The performance of a single-cylinder spark-ignition engine fuelled with both natural gas and gasoline has been measured. Both full-load and part-load performance has been compared over a speed range up to 4800 rpm. In a separate set of experiments measurements were made on a multicylinder engine.

RESULTS TO DATE:
The major differences between the two fuels is the greater spark advance required for natural gas due to its lower burning velocity. This increased spark advance resulted in a lower thermal efficiency for natural gas compared to gasoline over the complete speed and load range. In contrast, the specific fuel consumption was actually lower for natural gas since it had a lower heating value than that of gasoline. Cylinder pressure measurements and mass burn rate analysis indicated that the major effect of the low burning velocity of natural gas occurs in the early phase of combustion.

REPORTS/PUBLICATIONS:
R.L. Evans, F. Goharian and P.G. Hill, "The Performance of a Spark-Ignition Engine Fuelled with Natural Gas or Gasoline", SAE 840234.
R.L. Evans, A.L. Jones and R. Kukula, "A Comparison of Natural Gas and Gasoline in a Spark-Ignition Engine", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C., Aug. 7-10, 1986.

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PROJECT TITLE: DUAL FUELLING OF A DIESEL ENGINE WITH NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance of a turbocharged prechamber diesel engine operating on natural gas.

METHOD:
A Caterpillar 3308 turbocharged prechamber diesel was operated with natural gas injection at the turbocharger inlet and with diesel pilot ignition over a wide range of loads and speeds.

RESULTS TO DATE:
Engine specific fuel consumption and peak pressures were determined as a function of pilot diesel fraction of total energy input and of load and speed. Retarding diesel injection timing help to reduce maximum pressures. Limited intake air throttling provided some reduction in fuel consumption at peak load. At full load fuel consumption tended to be somewhat less than for straight diesel operation.

REPORTS/PUBLICATIONS:
S. Song, "Performance of a Dual-Fuel Pre-Chamber Diesel Engine with Natural Gas", ASME J. Eng. for Power, 1985.
X. Ding and P.G. Hill "Emissions and Fuel Economy of a Prechamber Diesel Engine with Natural Gas Duel Fuelling", SAE 860069, 1986.

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PROJECT TITLE: PERFORMANCE OF A SPARK IGNITION ENGINE WITH GASOLINE AND NATURAL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	FLAME-PROP IGN-QUALITY		

OBJECTIVES:
To determine the burning rates in a spark ignition engine fuelled with natural gas or gasoline.

METHOD:
Measurements were made of pressure rise due to combustion in a four-cylinder engine, and burning rates were deduced from a heat release model.

RESULTS TO DATE:
The low burning velocity of natural gas increases the main combustion period by up to 10% more than that of gasoline. Ignition delay period increases are of the order of 100%.

REPORTS/PUBLICATIONS:
A.L. Jones and R.L. Evans, "Comparison of Burning Rates in a Natural-Gas-Fuelled Spark Ignition Engine", ASME J. Eng. for Power, 1985.

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PROJECT TITLE: NATURAL GAS FUELLING OF A PRECHAMBER DIESEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	

OBJECTIVES:
To measure the emissions and fuel consumption of a turbocharged pre-chamber diesel engine with dual fuelling of naturally aspirated natural gas and diesel pilot ignition.

METHOD:
A four cylinder turbocharged prechamber diesel engine (Caterpillar 3304) was operated with natural gas and pilot diesel ignition over a wide range of load and speed. Measurements were made of fuel consumption and the emissions of unburned hydrocarbons, carbon monoxide, and the oxides of nitrogen.

RESULTS TO DATE:
Improvements in fuel economy and emissions were found to be affected by the diesel gas energy fraction, and by air restriction and diesel injection timing.

Boundaries of unstable, inefficient and knocking operation were defined and the importance of gas-air equivalence ratio was demonstrated in its effect on economy, emissions and stability of operation.

REPORTS/PUBLICATIONS:
X. Ding and P.G. Hill "Emissions and Fuel Economy of A Prechamber Diesel Engine with Natural Gas Duel Fuelling", SAE 860069, 1986.

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PROJECT TITLE: SQUISH-GENERATED TURBULENCE IN S.I. ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	FLAME-PROP IGN-QUALITY	FUEL-CONSUMPTION	

OBJECTIVES:
To evaluate the effect of a new design of squish chamber on spark ignition engine performance with natural gas fuelling.

METHOD:
Experiments were performed with a single cylinder C.F.R. engine to provide data for the evaluation of the squish designs. Several reference squish chambers were manufactured for the C.F.R. engine. Flow field data was obtained via hot wire anemometer measurements taken in the cylinder during motored operation of the engine. Pressure data recorded while the engine was operated on natural gas yielded mass burn rate information.

RESULTS:
Mass burn rate analysis of cylinder pressure data shows the squish design to have greatest impact on the main combustion period (2% to 85% mass burned). A comparison of the reference squish design in these experiments to the disc chamber shows a 32% reduction in the combustion duration and a 30% increase in peak pressure occurring 5 crank angle degrees earlier. The squish-jet design provided the additional effect of a reduction in the ignition delay time (spark to 2% mass burned). The squish-jet design resulted in a reduction of the ignition delay time by 3 crank angle degrees and in a 4% increase in peak pressure occurring 3 crank angle degrees earlier compared to the reference squish chamber. The total combustion duration was 5% less with the squish-jet design.

REPORTS/PUBLICATIONS:
C.D. Cameron "An Investigation of Squish-Generated Turbulence in I.C. Engines", Department of Mechanical Engineering, University of B.C., Report AFL-85-02, 1985.

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PROJECT TITLE: DUAL FUEL ENGINE COMBUSTION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS PROPANE/LPG HYDROGEN	KNOCK-LIMITS	EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY	

OBJECTIVES:
To review the combustion characteristics of the dual-fuel engine with methane, liquefied natural gas, propane, hydrogen, or ethylene as fuels with diesel pilot ignition.

REPORTS/PUBLICATIONS:
Karim, Ghazi A., "A Review of Combustion Processes in Dual Fuel Engine - The Gas Diesel Engine", Proc. National Conference on I.C. Engines and Combustion, 1978, 18pp.

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PROJECT TITLE: SAFETY OF ENGINE OPERATION WITH NATURAL GAS, GASOLINE, PROPANE AND HYDROGEN

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS PROPANE/LPG HYDROGEN			REFUELLING TANKS-ON-BOARD

OBJECTIVES:
To assess the relative safety of operation of automotive engines with natural gas, gasoline, propane and hydrogen fuels.

RESULTS TO DATE:
The total number of vehicles fuelled with compressed natural gas, CNG, is relatively very small in comparison to gasoline fuelled vehicles. Accordingly, because of the lack of statistics of accidents involving CNG fuelled vehicles, their safety aspects are evaluated in comparison to propane, hydrogen, LNG or LH2. It is suggested that methane, CNG, has some excellent physical, chemical and combustion characteristics that make it a safe automotive fuel. These characteristics are reviewed and the superior relative safety of methane in automotive applications in comparison to applications involving the other fuels is demonstrated where well designed conversion systems and operations are employed.

REPORTS/PUBLICATIONS:
Karim, G.A., "Some Considerations of the Safety of Methane, (CNG), as an Automotive Fuel - Comparison with Gasoline, Propane and Hydrogen Operation", SAE Technical Paper No. 830267, 7 pp., 1983.

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PROJECT TITLE: NATURAL GAS FOR DIESEL ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS	KNOCK-LIMITS	EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	

OBJECTIVES:
To review the problems associated with the use of natural gas, notably methane in dual-fuel engines of the compression ignition diesel type.

RESULTS TO DATE:
It is shown that such applications represent a very attractive mode for the utilization of the fuel for the production of power generally at relatively high efficiencies and outputs with superior emissions characteristics. Some of the problems associated with such applications are discussed and some relevant solutions outlined.

REPORTS/PUBLICATIONS:
Karim, G.A. "Some Considerations of the Use of Natural Gas in Diesel Engines", Symp. on Nonpetroleum Vehicular Fuels III, Arlington, VA., 17 pp., 1982.

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PROJECT TITLE: COMBUSTION IN THE DUAL FUEL ENGINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS	KNOCK-LIMITS FLAMM-LIMITS	EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	

OBJECTIVES:
To assess the characteristics of combustion in diesel engines with dual fuelling with natural gas.

RESULTS TO DATE:
A brief review has been made of the characteristics of the dual fuel engine of the compression ignition type and the combustion phenomena that brings about such characteristics. Operation with liquefied natural gas (LNG) and under low intake temperature is also considered.

REPORTS/PUBLICATIONS:
Karim, G.A., "A Review of Combustion Processes in the Dual Fuel Engine - The Gas Diesel Engine", Prog. Energy Combust. Sci. Vol.6, pp.277-285, 1980.

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PROJECT TITLE: DUAL FUELLING OF A DIESEL ENGINE WITH VARIABLE GAS COMPOSITION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	

OBJECTIVES:
To determine the effect on performance of a dual-fuelled (natural gas) diesel engine with varying proportions of H, CH, CO and N in the intake.

METHOD:
An examination of the combustion phenomena and associated engine performance is made for the dual fuel engine of the compression ignition type when additional auxiliary fuels and inerts were introduced with the main intake charge. This was considered to have direct relevance to operation of diesel engine on low heating value gaseous fuel mixtures. A single cylinder direct injection diesel engine was employed throughout. H_2, CH_4, CO_2 and N_2 were the gas constituents used.

RESULTS TO DATE:
Operation on gaseous fuel mixtures containing significant amounts of diluent inerts showed a marked deterioration of the already inefficient combustion of lean fuel-air mixtures. Of the two inert gases (CO_2 and N_2) introduced in turn, CO_2 has a comparatively greater influence in narrowing the operating range of the engine.

Both diesel and dual fuel operations were also considered when a spray of water was introduced into the intake of the engine. The quenching of the charge resulting from water addition appeared to slow down the combustion rates, necessitating the supply of a certain minimum amount of gaseous fuel and diesel pilot for adequate combustion.

REPORTS/PUBLICATIONS:
Karim, G.A., Amoozegar, N., "Examination of the Performance of a Dual Fuel Diesel Engine with Particular Reference to the Presence of Some Inert Diluents in the Engine Intake", SAE 821222, 1982.

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PROJECT TITLE: METHANE AND PROPANE FOR SPARK IGNITION ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL SPARK IGNITION	PROCESS GAS PROPANE/LPG	KNOCK-LIMITS LUMINOSITY	EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	REFUELLING TANKS-ON-BOARD COLLISION

OBJECTIVES:
To compare the performance of methane and propane in spark-ignition and compression-ignition engines.

METHOD:
Results of comparative tests involving spark ignition engines over a wide range of operating conditions are presented and discussed. Some of the performance characteristics considered are those relating to power output, efficiency, tendency to knock, cyclic variations, optimum spark requirements and exhaust emissions.

Similarly, some of the performance characteristics in compression ignition engines considered include power output, efficiency, tendency towards knock and autoignition, exhaust emissions and low operational temperature problems.

Finally, the relative operational safety aspects of the two fuels are evaluated. It is then suggested that in this regard methane has some excellent physical, chemical and combustion characteristics that makes it a particularly safe fuel.

REPORTS/PUBLICATIONS:
Karim, G.A., Wierzba, I., "Comparative Studies of Methane and Propane as Fuels for Spark Ignition and Compresion Ignition Engines", SAE Special Publication No.SP-548, pp.26-37, 2983.

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PROJECT TITLE: DUAL FUELLING OF DIESEL ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS	KNOCK-LIMITS FLAME-LIMITS	FUEL-CONSUMPTION DUAL-FUELLING OPERABILITY DURABILITY	

OBJECTIVES:
To assess the main problems of operation of natural gas in dual-fuelled diesel engines with pilot ignition.

RESULTS TO DATE:
A review has been made of some of the main problems associated with the use of natural gas, notably methane, in dual fuel engines of the compression ignition diesel type. It is shown that such applications represent in principle a very attractive mode for the utilization of the fuel for the production of power generally at relatively high efficiencies and outputs with good exhaust emissions characteristics. Some relevant solutions to the problems outlined are then discussed. Moreover, some further research and development needed in this general area is also outlined.

REPORTS/PUBLICATIONS:
Karim, G.A., "The Dual Fuel Engine of the Compression Ignition Type - Prospects, Problems and Solutions - A review", SAE Paper No. 831073, pp.71-79.

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PROJECT TITLE: DUAL FUELLING OF A DIESEL ENGINE WITH LIQUID FUELS ADDED TO THE INTAKE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	NATURAL GAS		EMISS-EXHAUST FUEL-CONSUMPTION DUAL-FUELLING	

OBJECTIVES:
To determine the effects of addition of liquid fuels to the intake of a diesel engine dual fuelled with natural gas, and with diesel pilot ignition.

METHOD:
An examination of the engine performance and associated combustion was made for a dual fuel engine of the compression ignition type when additional auxiliary fuels were introduced in turn in the form of a spray into the main intake charge with methane being the main fuel. This was attempted with the view of modifying the dual fuel engine behaviour particularly at light load. Alcohols, gasoline, benzene or normal hexane were introduced in turn to various extents into the intake charge of the engine. Comparison with dual fuel operation on a range of gaseous fuels and with water spray injection was made.

RESULTS TO DATE:
Gasoline, benzene or n-hexane intake addition reduced the overall ignition delay significantly and increased the power output of the dual fuel diesel engine at light load. This, however, was achieved at the cost of undermining the efficiency of fuel utilization at higher loads. Moreover, the quenching of the charge resulting from water or alcohols additions appeared to slow down the combustion rates necessitating the supply of a certain amount of gaseous fuel and diesel pilot fuel injection for a threshold of adequate combustion.

REPORTS/PUBLICATIONS:
Karim, G.A., Amoozegar, N., "Determination of the Performance of a Dual Fuel Diesel Engine with the Addition of Various Liquid Fuels to the Intake", SAE, 1983, 10 pp.

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PROJECT TITLE: IGNITION LIMITS WITH METHANE FUELLING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	FLAME-LIMITS IGN-QUALITY		

OBJECTIVES:
To determine the range of ignition limits for a spark ignition engine fuelled with natural gas.

RESULTS TO DATE:
The observed lean ignition limits of homogeneous methane-air mixtures in a spark ignition engine over a wide range of compression ratios and intake temperatures are amenable to correlation on the basis of the mean mixture temperature at the time of passing the spark. The corresponding rich limits could also be correlated in terms of the rise in the mean mixture temperature during compression. Attention to the reduction of heat losses during compression would aid in extending the limits.

REPORTS/PUBLICATIONS:
G.A. Karim and I. Wierzba "The Ignition Limits in a Spark Ignition Engine Fuelled with Methane", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, Aug.7-10, 1986.

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PROJECT TITLE: PERFORMANCE OF A TWO-STROKE DIESEL ON TAR SANDS DERIVATIVE FUEL

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To characterize the behaviour of a two-stroke, turbocharged medium speed diesel engine (GM 6V53T) when operated on tar sands (off-specification) derived fuels.

METHOD:
The work to date includes performance/combustion behaviour of four fuels (including the NRC 1990 diesel fuel), thermodynamic model correlation with experimental data, scavenging/compression-expansion multi-dimensional analyses and the experimental measurement of the flow field, during scavenging, in the engine.

RESULTS TO DATE:
Full load and part load brake, indicated and combustion characteristic performance curves plus fuel-to-fuel comparison plots of each parameter have been generated. The most informative presentation format was found to be parameter maps contoured over the complete operating range of the engine. Concern exists over the compatibility of the off-specification fuels due to high pressure rates and gas vibrations which occur over large operating ranges of the engine. Thus, the engine is being instrumented with vibration and acoustic monitors so as to measure the physical response of the engine versus combustion pressure rate.

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PROJECT TITLE: PROPERTIES OF ALCOHOL GASOLINE BLENDS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	OXY-WITH-GASOLINE	KNOCK-LIMITS		

OBJECTIVES:
To determine the physical properties of blends of gasoline with methyl fuel-MBTE (Methyl tertiary butyl ethane) or ethanol-MBTE

METHOD:
Properties determined were water tolerance at room temperature, Reid vapour pressure, specific gravity, distillation curves, octane number, heating value.

RESULTS TO DATE:
The MBTE content has little effect on water tolerance of the various gasoline alcohol blends, if MBTE is less than 10% of the oxygen containing components. Larger percentages of MBTE increase the water tolerance of the methanol or methyl fuel-gasoline blends but cause a decrease in the ethanol-gasoline mixtures.

REPORTS/PUBLICATIONS:
"Physical Properties and Phase Separation of Alcohol-Gasoline Blends", Energy Mines and Resources Canada Report TE-83-6, 1983.

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PROJECT TITLE: LOW CETANE DIESEL FUEL/ENGINE INTERACTION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL		IGN-QUALITY SPRAYS	OPERABILITY	

OBJECTIVES:
Study the effects of low cetane fuel containing tar sands derived components on the performance of a 6V53T Detroit diesel engine

METHODOLOGY:
A broad research program has been established around the operation of the 2-stroke, turbo charged 6V53T diesel engine on low cetane number fuels (35 and 37). The program includes:-

- Brake and indicated performance measurement
- Combustion characteristics (e.g. P-CA curves)
- Correlation of engine response with combustion behaviour
- Evaluation of combustion control by fuel injection control
- Analytical modelling of combustion and ignition delay
- Thermodynamic model/parametric study
- Experiments on ignition of single droplets of 2-component liquid fuels
- Modelling of 2-component liquid droplet ignition
- 2-dimensional laminar model of the compression-expansion stroke using a moving co-ordinate system
- Assessment of scavenging efficiency and scavenging ratio using 2 and 3-D laminar and turbulent models
- Evaluation of scavenging in a 2-stroke diesel using 2 and 3-D laminar and steady-state models
- Measurement of mean and turbulent velocity fields during scavenging.

SIGNIFICANCE:
Basically same as NRC Diesel Program

STATUS:
Ongoing.

RESULTS:
- The brake and indicated performance characteristics and cylinder peak pressures showed no substantial change with decrease in cetane number.- Substantially different cylinder pressure characteristics however were revealed with high pressure rates and attendant pressure waves.- A thermodynamic model was developed for the two-stroke engine which gave accurate projections (IHP, peak pressure, etc.) at maximum load.- Increasing errors were produced as the load was decreased and the model was particularly weak in predicting the "rapid combustion" at part load.
- Modifications to the combustion model to involve a correlation with engine load as well as speed and an explicit ignition delay model for part load operation should be developed.

REFERENCES:
1. Flanagan, R.C. and Menard, L., "A Study of Wide Boiling Range Fuel - Engine Interaction: Engine Performance and Combustion Monitor Tests" Contract Report No. 2SU81-00088, Technical Report No. U)ME-EP-8403-1, Department of National Defence, DREO, Ottawa, Ont. 1984, 199 pp.
2. Flanagan, R.C., and Menard, L., "Effects of Fuel Quality on the Performance of a High Speed Diesel Engine: Brake and Indicated Characteristics", SAE p-155, pp.89-102, March 1985, presented at the ATD-CCM Meeting, Detroit.
3. Menard, L. and Flanagan, R.C., "Effects of Fuel Quality on the Performance of a High Speed Diesel Engine: Combustion Parameter Characteristics", SAE P=155, pp.103-117, March 1985, presented at the ATD-CCM Meeting, Detroit.
4. Flanagan, R.C. and Menard, L., "Combustion Characteristics of Tar Sands Derived Fuels in a Two-Stroke Turbocharged Diesel", Proceedings: Future Diesel Fuels, Their Analysis and Correlations with Engine Performance and Combustion, Ottawa, Ont. Oct. 1984, 22 pp.
5. Flanagan, R.C., Salcudean, M., Xia, Y.Q., and Carapanayotis, A., "A Study of Wide Boiling Range Fuel-Engine Interaction: Thermodynamic and Multidimensional Modeling", Contract Report No. 2SU82-000396, Technical Report No. UOME-EP-8404-1, Department of National Defence, DREO, Ottawa, Ont. 1984, 195 pp.
6. Flanagan, R.C., Carapanayotis, A. and Xia, Y.Q., "Thermodynamic Simulation of a Two-Stroke Direct Injected Turbocharged Diesel", Proceedings, IASTED International Conference: Applied Simulation and Modeling, Montreal, June 1985, 5 pp.
7. Flanagan, R.C., Xia, Y.Q., Menard, L. and Carapanayotis, A., "Indicated Performance Comparisons between Thermodynamic Model Predictions and ExmaMeasurements on a Two-Stroke Turbocharged Diesel", Proceedings IASTED International Conference: Applied Simulation and Modeling, Montreal, 1985, 5 pp.

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PROJECT TITLE: IGNITION OF MULTICOMPONENT LIQUID FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	TAR SANDS DERIV	IGN-QUALITY		

OBJECTIVE:
Future petroleum fuels, especially those produced from tar sands, are expected to have physical and chemical properties differing from those of present fuels. As an aid in understanding the ignition behaviour of such fuels in engines, both experimental and theoretical studies of the ignition of single droplets of pure fuels and two-component fuel mixtures are being undertaken. A numerical model of the ignition process has been developed which gives good predictions of measured ignition delays for single component fuels. This model is now being extended to two component mixtures. This work is sponsored by DND, NSERC and Imperial Oil.

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PROJECT TITLE: CANOLA OIL AS FUEL FOR FARM DIESEL ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	OTHER		COLD START LUBRICANTS OPERABILITY DURABILITY	

OBJECTIVE:
To determine the technical feasibility of using canola oil as a diesel fuel or a diesel fuel extender for farm engines.

METHODOLOGY:
- Methods of improving the low temperature properties of canola oil such as by dilution with diesel fuel and/or alcohol, conversion to the methyl ester and use of pour depressants were investigated.
- Engine tests using a Petter two cylinder and a John Deere six cylinder engine were conducted including runs on canola oil, blends of canola oil and diesel fuel/alcohol and conversion to the methyl ester.

SIGNIFICANCE:
The engine tests will determine the feasibility of using canola oil to supplement diesel fuel use in localized agricultural operations.

STATUS:
Program completed.

RESULTS:
- The low temperature characteristics of canola oil would limit its fuel use to 0 C. Temperatures below 0 C would require dilution with diesel fuel or fuel heat.
- Short runs (up to 30 hrs) were reasonably satisfactory with both engines. Longer runs of 300 hrs. with the Petter engine produced serious cylinder deposits and seized rings (longer runs not extended to the John Deere engine because of anticipated damage).
- In addition to the above, many conclusions were reached which are included in references. In general, these conclusions point to canola being an unsatisfactory diesel fuel replacement/supplement.

REFERENCES:
"Canola Oil as Fuel for Farm Diesels", Phase I by R. Strayer et al., Sept. 1981, Program File #3452.01706-0-0100. Phase II by R. Strayer et al, April 1983, Program File #23SU01843-1-EL05. Engineering & Statistical Research Institute, Agriculture Canada, Ottawa, Ontario.

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PROJECT TITLE: PERFORMANCE OF A DIESEL ENGINE WITH DIRECT INJECTION OF PROPANE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG		FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To determine the performance of a diesel engine fuelled by direct injection of liquid propane with ignition by either glow plug or diesel pilot injection.

METHOD:
Experiments have been carried out with a single-cylinder Waukesha CFR cetane rating engine (prechamber diesel) fuelled by injected liquid propane. Performance and emissions data have been obtained for tests carried out with glow plug ignition and for tests with ignition by diesel pilot injection.

RESULTS TO DATE:
Fuelling with propane results in significantly less exhaust smoke than the original diesel. For the same level of smoke opacity, the liquid propane injection engine produced about 15% more power. With ignition by diesel pilot injection, only about 10-15% of the total fuel energy had to be provided by the diesel pilot to maintain good ignition and stable operation at the compression ratios tested (19:1, 22:1 and 25:1). Liquid propane injection with glow plug ignition allowed complete substitution of propane for diesel fuel and provided excellent results at 25:1 compression ratio. However, at the two lower compression ratios, it was not possible to obtain reliable ignition at loads below about two-thirds of full load. It is believed that reliable ignition can be attained under all engine operating conditions with some additional development. The efficiency of the liquid propane-injected engine (both the glow plug and diesel pilot versions) was nearly the same as that of the original diesel. Hydrocarbon emissions with liquid propane injection are nearly the same as those of the original diesel, while NOx emissions are lower.

REPORTS/PUBLICATIONS:
J.S. Wallace, U. Oester, J.H. Morgan, "Performance and Emissions of a Propane-Fuelled Diesel Engine", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug.7-10, 1986.

Oester, W., Wallace, J.S., Segal, L. and Keffer, J.F., "Propane-Fueled Diesel Engines", Final Report to SNC Inc., June 1986.

Oester, W., Segal, L., Wallace, J.S. and Keffer, J.F., "Combustion Characteristics of Propane Directly Injected into Diesel Engines", Final Report to Transportation Development Centre, Transport Canada, June 1986.

Additional publications in preparation.

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PROJECT TITLE: STORAGE OF COMPRESSED NATURAL GAS AND HYDROGEN

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS HYDROGEN	OTHER	OTHER	

OBJECTIVES: To compare the merits of compressed natural gas and hydrogen as alternative vehicle fuels.

METHOD:
CNG and compressed hydrogen are compared to illustrate why CNG, but not compressed hydrogen, is a viable alternative vehicle fuel.

RESULTS TO DATE:
It has been shown that natural gas has a greater energy content per mole than hydrogen and that more moles of natural gas than hydrogen may be stored in a given volume under identical conditions. Natural gas stored at 20.78 MPa (3000 psig) and 21.1 C (70 F) contains five times as much energy as hydrogen stored under the same conditions. Natural gas stored in a representative size CNG cylinder provides a range of about 100 km, while hydrogen in the same cylinder would provide a range of only 26 km, even assuming 30% greater efficiency from the hydrogen-fuelled engine.

REPORTS/PUBLICATIONS:
Wallace, J.S., "A Comparison of Compressed Hydrogen and CNG Storage", Int. J. Hydrogen Energy, Vol.9, No.7, pp.609-611, 1984.

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PROJECT TITLE: TESTING AND EVALUATION OF AUTOMOTIVE PROPANE AND NATURAL GAS CONVERSION EQUIPMENT

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS PROPANE/LPG		FUEL-CONSUMPTION	

OBJECTIVES:
To evaluate commercially available conversion kits.

METHOD:
Engine dynamometer tests.

RESULTS TO DATE:
Report on research conducted by the University of Toronto Engine Research Development Laboratory (ERDL). Tests were conducted to evaluate the performance, fuel economy and emission characteristics of natural gas fuelled engines which had been converted using four commercially available kits. It was found that there are significant differences in power and torque output and fuel efficiency for the kits, for both propane and CNG conversions. ERDL concluded that the universal regulators and mixers currently used for both CNG and propane do not ensure proper mixing.

REPORTS/PUBLICATIONS:
PROPANE/LPG:
Wallace, J.S. and Segal, L., "Consolidation and Assessment of Propane Equipment Test Results", Final Report to Ontario Ministry of Transportation and Communications, March 1986.

Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Propane Conversion Equipment", Phase V, Final Report to Ontario Ministry of Transportation and Communications, May 1983.

Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Propane Conversion Equipment", Phase IV, Final Report to Ontario Ministry of Transportation and Communications, June 1982.

Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Propane Conversion Equipment", Phase III, Final Report to Ontario Ministry of Transportation and Communications, June 1981.

Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Propane Conversion Equipment", Phase II, Final Report to Ontario Ministry of Transportation and Communications, December 1980.

NATURAL GAS:
Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Natural Gas Conversion Equipment", Phase II, Final Report to Ontario Ministry of Transportation and Communications, March 1985.

Segal, L. and Keffer, J.F., "Testing and Evaluation of Automotive Natural Gas Conversion Equipment", Phase I, Final Report to Ontario Ministry of Transportation and Communications, February 1984.

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PROJECT TITLE: DESIGN OF SAFE HYDROGEN FUEL SYSTEM FOR ENGINE TESTING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	HYDROGEN			OTHER

OBJECTIVES:
Design of a safe hydrogen fuel system for dynamometer testing of hydrogen-fuelled engines

METHOD:
Design according to applicable codes and standards.

RESULTS TO DATE:
Completed system has been used safely for two years.

REPORTS/PUBLICATIONS:
Segal, L., Wallace, J.S. and Keffer, J.F., "Safety Consideration in the Design of a Gaseous Fuel Supply for Engine Testing", accepted for publication by the "International Journal of Hydrogen Energy", 1986.

Segal, L., "Safety Considerations in the Design of a Gaseous Hydrogen Fuel Supply - A Case Study", Final Report to Institute for Hydrogen Systems, 1984.

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PROJECT TITLE: DIRECT INJECTION HYDROGEN INTO A C.I. ENGINE WITH GLOW PLUG IGNITION

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	HYDROGEN		EMISSIONS FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
Evaluate the performance and emissions of a direct-injection diesel engine fueled by gaseous hydrogen injected at high pressure and ignited by a continuously operating glow plug.

METHOD:
Engine dynamometer tests of a single-cylinder DI diesel.

RESULTS TO DATE:
Compared to operation on diesel fuel, the hydrogen-fuelled engine was capable of providing about 40% more indicated power at 1200 rpm and 30% more at 1800 during transient operation. However, heat transfer problems specific to this experiment limited the practical power output to the same level as the diesel-fuelled engine. Despite being at a very early stage of development, the indicated efficiency of the hydrogen-fuelled engine is about 90% of that attained on diesel fuel over most of the load range. Improvements in efficiency can result from further refinement of the combustion chamber and injector geometry.

REPORTS/PUBLICATIONS:
Final paper still being prepared - to be submitted to IJHE.

Welch, A.B. and Wallace, J.S., "Development of a Hydrogen Injector for Use in Hydrogen-Fueled Diesel Engine Research", Proceedings of the 21st Intersociety Energy Conversion Engineering Conference, August 25-29, 1986, San Diego, CA.

Welch, A.N. and Wallace, J.S. "Performance Characteristics of a Hydrogen-Fueled Diesel Engine with Ignition Assist", Final Report to National Research Council of Canada, March 1986.

Wallace, J.S., "Hydrogen-Fueled Diesel Engine Test Results", Communication at the International Energy Agency Hydrogen Task VII Workshop, Bern, Switzerland, June 12-13, 1985.

Wallace, J.S. "Direct Injection Hydrogen-Fueled Diesel Engine Tests", communication at the International Energy Agency Hydrogen Task VII Workshop, Toronto, July 12-13, 1984.

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PROJECT TITLE: HYDROGEN FUELLING OF SPARK IGNITION ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	HYDROGEN		EMISSIONS FUEL-CONSUMPTION OPERABILITY DURABILITY	

OBJECTIVES:
1. Evaluate the feasibility of using hydrogen-fueled engines in road vehicles;
2. evaluate the operability of hydrogen-fuelled spark ignition engines;
3. evaluate the durability of hydrogen-fuelled spark ignition engines in simulated short trip operation.

METHOD:
1. Literature review.
2 and 3. Engine dynamometer tests of a 1.6 litre four-cylinder spark ignition engine.

RESULTS TO DATE:
1. Combinations of onboard hydrogen storage forms and engine fuelling methods with potential for further development were identified and recommendations made for necessary research and development.
2. Measurements of hydrogen peroxide and unburned hydrogen were used to determine the minimum equivalence ratio that can be used in a quality-governed hydrogen-fuelled spark ignition engine. Operability (limited by the occurrence of intake manifold flashback) was evaluated at higher equivalence ratios in a worn engine. Flashbacks were found to occur at equivalence ratios as low as 0.4.
3. Project still in progress.

REPORTS/PUBLICATIONS:

1. Wallace, J.S., "Update of Hydrogen Fuel/Engine Systems Feasibility Study", Final Report to Institute for Hydrogen Systems, March 1985.

Wallace, J.S. and Keffer, J.F., "Evaluation and Testing of Hydrogen Fuel Engine Systems", Phase I, Final Report to Ontario Ministry of Transportation and Communications, January 1981.

2. Wallace, J.S., Segal, L. and Keffer, J.F., "Lean Mixture Operation of Hydrogen-Fueled Spark Ignition Engines", communication at the SAE Fuels and Lubricants Meeting, Tulsa, Oklahoma, October 21-24, 1985.

Wallace, J.S., Segal, L. and Keffer, J.F., "Hydrogen Fuel/Engine Systems", Phase III, Final Report to Ontario Ministry of Transportation and Communications, March 1985.

3. Project still in progress.

Wallace, J.S., "Hydrogen Fueled Engine Durability Considerations", Proceedings of the 2nd International Symposium of Hydrogen Produced from Renewable Energy, Cape Canaveral, Florida, October 22-24, 1985.

ORGANIZATION: UNIVERSITY OF TORONTO (7)
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PROJECT TITLE: COLD STARTING OF METHANOL-FUELLED S.I. ENGINES

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	METHANOL		COLD START	

OBJECTIVES:
Evaluate the feasibility of improving the cold starting of methanol-fuelled spark ignition engines through the use of on-board fuel processing.

METHOD:
Engine dynamometer tests of a single-cylinder CFR engine equipped with a refrigeration system to simulate operation at temperatures as low as -20 C.

RESULTS TO DATE:
Project still in progress.

REPORTS/PUBLICATIONS:
Kozole, K.H. and Wallace, J.S., "Improved Cold Starting with Methanol Through On-board Fuel Processing", communication at the Spring Technical Meeting, Canadian Section, The Combustion Institute, Waterloo, Ontario, May 30-31, 1985.

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PROJECT TITLE: OPERABILITY AND EMISSIONS OF A S.I. ENGINE WITH DECOMPOSED METHANOL FUEL GAS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	OTHER		EMISSIONS EMISS-EXHAUST FUEL-CONSUMPTION OPERABILITY	

OBJECTIVES:
To evaluate the operability and emissions of a spark ignition engine operating on decomposed methanol fuel gas (2/3 hydrogen, 1/3 carbon monoxide by volume) at compression ratios ranging from 9:1 to 14:1

METHOD:
Engine dynamometer tests of a single-cylinder CFR engine.

RESULTS:
Brake efficiency improvements of up to 22% over gasoline were recorded at light loads, but the maximum brake power output was only 74% of that attained using gasoline. A compression ratio in the range 9:1 to 10:1 was found to be the maximum that can be used without encountering knock and other more severe forms of abnormal combustion. The CO emissions were found to increase significantly as the equivalence ratio was decreased and may impose a practical lower limit on the extent to which quality governing can be employed. Tests utilizing a timed fuel injector in the intake port suggest that, once optimized, a throttled, liquid methanol-fuelled engine may equal the efficiency attained on dissociated methanol at light loads and may be the most attractive means of utilizing methanol in transportation applications.

REPORTS/PUBLICATIONS:
Anthonissen, E. and Wallace, J.S., "EC Engine Performance on Fuel Gas Produced by Catalytic Decomposition of Methanol. I-Hydrogen-Carbon Monoxide Mixtures", Final Report to Ontario Ministry of Transportation and Communications, July 1983 and communication at Spring Technical Meeting, Canadian Section, The Combustion Institute, Kingston, May 9-10, 1983.

Wallace, J.S., "Decomposed Methanol Engine Testing Results", communication at DOE Decomposed Methanol Workshop, Windsor, Ontario, July 9, 1983.

Anthonissen, E. and Wallace, J.S., "Dissociated Methanol Engine Testing Results Using the H2-CO Mixtures", Proceedings of 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 21-26, 1983.

ORGANIZATION: UNIVERSITY OF TORONTO (9)
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PROJECT TITLE: COMBUSTION CHARACTERISTICS OF PROPANE DIRECTLY INJECTED INTO DIESEL ENGINES"

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	PROPANE/LPG	SPRAYS	COLD START FUEL-CONSUMPTION	

OBJECTIVE:
To investigate the use of propane in a diesel engine with either glow plug or diesel pilot ignition or with direct cylinder injection and glow plug ignition.

METHOD:
A single-cylinder prechamber diesel engine was used to investigate propane fueling of diesel engines. Liquid propane was pumped to a high pressure and injected directly into the engine's prechamber at approximately the same time as diesel fuel would be injected in the original diesel engine. A continuously operating glow plug was used to provide ignition since propane has a very low cetane number. Tests were carried out at three compression ratios, 19:1, 22:1, and 25:1 and at three engine speeds, 1200, 1500 and 1800 rpm.

RESULTS:
For the same level of smoke opacity as the original diesel engine, the liquid propane injection engine produced about 15% more power. The relative position of the glow plug and fuel spray was critical to obtaining reliable ignition and short ignition delays. The final arrangement tested provided excellent results throughout the engine's operating range at 25:1 CR. However, at the two lower compression ratios, ignition was irregular at loads below about two-thirds of full load. At 25:1 compression ratio, the full load indicated specific fuel consumptions were 11 MJ/kw x h and 8 MJ/kW x h for diesel, liquid propane injection and propane fumigation (carbureted propane, pilot diesel ignition) respectively.

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PROJECT TITLE: HIGH ENERGY IGNITION WITH NATURAL GAS FUELLING

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
SPARK IGNITION	NATURAL GAS	IGN-QUALITY		

OBJECTIVES:
To assess the usefulness of high energy ignition for combustion of natural gas in spark-ignition engines.

RESULTS TO DATE:
A review has been made of plasma jet ignition and puff jet ignition. Plasma jet devices discharge electrical energy in the order of a few joules through a specially designed cavity. This produces a highly turbulent plume whose length is of the order of centimeters, and which forms a rapidly expanding ignition kernel in a combustible mixture. Puff jet igniters produce a puff of gaseous fuel which is injected directly into the engine cylinder and passes through a conventional low energy spark gap. The interesting fact is that both of these devices cause essentially the same type of ignition (as observed in high speed Schlieren photographs). The net result for automotive engines is that overall combustion is speeded up and engine timing becomes considerably less critical by comparison to standard modern ignition systems.

REPORTS/PUBLICATIONS:
R.M. Clements, P.L. Pitt and J.D. Ridley, "A Review of High Energy Ignition Techniques for Alternative Automotive Fuels", Proc. Conf. on Gaseous Fuels for Transportation, Vancouver, B.C. Aug.7-10, 1986.

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PROJECT TITLE: ATOMIZATION OF LIQUID FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
DIESEL	OTHER	SPRAYS		

OBJECTIVES:
Our research on alternative fuels focusses on:
Studying the effect of atomization parameters on flame performance in order to develop control strategies for burning liquid fuels of varying properties.

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PROJECT TITLE: FUEL FORWARDING & EMISSIONS FROM BURNING NAPHTHA IN AN INDUSTRIAL GAS TURBINE

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(INDUST)	OTHER	VOLATILITY VISCOSITY OTHER	LUBRICANTS OPERABILITY	OTHER

OBJECTIVES:
To pump naphtha liquid to a combustion test rig and to measure the products of combustion for comparison with conventional fuels.

METHOD:
The high Reid Vapour Pressure (12 psi) and low distillation temperature (46x @ 10%) put the conventional fuel pump at risk due to cavitation and to seizing due to lack of lubricity (viscosity at -20xC was 0,679 cSt). Normally a lubricity agent would have been necessary and this would have masked the emission level of hydrocarbons. In addition pre-cooling of the fuel would have been necessary to delay the onset of cavitation. An alternative solution would be to install a centrifugal pump dedicated to this specific fuel.

It was desired to measure the emissions of NOx, CO, UHC and particulates deriving from the combustion of pure liquid naphtha in an industrial gas turbine combustor whilst concurrently injecting steam for the suppression of NOx. It was expected that the emissions of NOx would be lower than for distillate #2 oil, emissions of CO lower than for natural gas and particulates low, the latter due to the absence of ash in the fuel. After the seizure of a swash-plate, constant displacement pump, a lubricity agent was added which permitted limited testing to proceed. Later, a pitot-type centrifugal pump was used to forward the pure liquid naphtha. Tests were then successfully carried out which confirmed the expected emissions. The particulates were so low as to be indeterminate.

RESULTS TO DATE:
In order to forward liquid naphtha for use as a gas turbine fuel, the pitot-type pump has been shown to work successfully. This pump has two basic working parts: a rotating case and a stationary pick-up tube collector arm within the rotor.

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PROJECT TITLE: CRUDE AND RESIDUAL OILS AS GAS TURBINE FUELS

ENGINE TYPE(S)	FUEL(S)	PROPERTIES	ENGINE PERFORMANCE	SAFETY
GAS-TURB(INDUST)	OTHER	COMPOSITION SPRAYS	OPERABILITY	

OBJECTIVES:
Industrial gas turbines are, on occasion, required to burn crude and residual oils which can contain high concentrations of vanadium which must be removed by treating the fuel with an additive. This additive can, in association with fuel borne water, form a gel which results in thick hard deposits on the combustion chamber walls to the detriment of the wall-cooling

METHOD:
A program will imminently be underway at the NRC Gas Dynamics Laboratory to duplicate a fuel forwarding system to represent the actual problem and to develop a combustion chamber which will tolerate these deposits and recover the originally specified lives of engine component parts.

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Alternative Transportation Fuels: Review of Research Activity in Canada (4)

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SUMMARY/SOMMAIRE (15)

The results of a survey of Canadian research activities related to alternative propulsion fuels are presented. Current knowledge is summarized and future research needs identified for gas turbine and reciprocating engine fuels.

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